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PSYCHOLOGICAL CHARACTERISTICS OF THE ACTIVITY OF COSMONAUTS

by A. A. Leonov and [illegible]

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PSYCHOLOGICAL CHARACTERISTICS OF THE ACTIVITY OF COSMONAUTS

By A. A. Leonov and V. I. Lebedev

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ANNOTATION

A. A. Leonov, and V. I. Lebedev. Psychological Characteristics of the Activity of Cosmonauts, 1971.

In this volume A. A. Leonov, Pilot-Cosmonaut of the USSR, and V. I. Lebedev, Candidate of Medical Sciences, discuss the role of the cosmonaut in the man-spacecraft system, the importance of crew teamwork in controlling multiplace spacecraft, and the psychological aspects of the preparation of cosmonauts as operators. Shown are the changes in the environmental conditions and the associated psychophysiological mechanisms of space and time perception away from the earth as man goes into outer space. The influence of weightlessness, extended isolation in cramped quarters, emotional stress and other space flight factors on man's perception of time is explained. An analysis is made of man's motor activity under weightless conditions. The gains possible from integrating man and machine and training the cosmonauts for orientation during long space flights and also from organizing work and rest periods during interplanetary space flights are pointed out.

The book is intended for psychologists, philosophers, biologists, doctors, cosmonauts, pilots, and other specialists interested and involved in working out the problems of aviation and space psychology.

There are seven tables, 26 figures, and 198 references.

Responsible editor — Professor A. N. Leont'yev.

INTRODUCTION

> The human mind has discovered much that is amazing in nature and will discover still more, thereby increasing man's command over nature.
>
> V. I. Lenin

In one of his reports in the early days of the space era, Academician N. M. Sisakyan said, "It is difficult to avoid temptation and not try to compare our times with the epoch of the great geographical discoveries." This is truly the case. Following Gagarin, who opened man's road into space, newer and newer spacecraft with Soviet and American cosmonauts aboard have been launched into near-earth orbits. /5*

In the Soviet Union our natural satellite, the Moon, is being successfully studied with the aid of automatic vehicles. In 1970 the world's first mobile laboratory, Lunokhod-1, began to operate on the surface of the Moon. Automatic vehicles created in the Soviet Union are being sent regularly to Mars and Venus. The characteristics of the interplanetary medium and planetary atmospheres and surfaces are being studied with the aid of equipment installed aboard interplanetary probes.

The next step in conquering outer space is the creation of permanent manned orbital stations and flights of cosmonauts to some solar system planets. Such flights are possible with the aid of chemically fueled rockets, to say nothing of interplanetary probes with nuclear power plants.

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*Numbers in the margin indicate pagination in the original foreign text.

The large piloted interplanetary spacecraft with its equipment will be a complex multiloop control system with man in the loop. Here the basic cosmonaut functions will be observing the operation of automatic devices and systems, solving problems of space navigation, correcting the flight trajectory, preparing the spacecraft for landing on the particular celestial body, and so on. Moreover, the members of the interplanetary spacecraft crew will have to carry out a broad range of scientific investigations.

In the process of orbital and interplanetary flights man will be subjected to several unusual factors to which his organism has not adapted in the course of evolutionary development. Most important among these unusual factors are weightlessness, a system of space coordinates which differs from that used under terrestrial conditions, termination of the action of the terrestial time "sensors," and so on. /6

Even prior to man's flights into outer space psychology and the related sciences were already faced with the broad question: to what degree and how will adequate perception of reality be provided, including spatial and temporal relationships; how to provide the psychophysiological organization of man under new conditions to which he is not adapted.

In our previous book entitled Perception of Space and Time in the Cosmos, which appeared in 1968, we made an attempt to correlate the experimental data and experience of flights in satellite spacecraft, and this was of some assistance in answering the question posed above.

Since that volume was published, new advances have been made in conquering outer space. Thus, the two spacecraft Soyuz-4 and

Soyuz-5 were successfully linked up and the world's first orbital station was created. The Soyuz-6, 7, and 8 spacecraft have performed their flight program. The American astronauts have flown around the Moon and landed on the Moon's surface. Finally, the extended flight of A. Nikolayev and V. Sevast'yanov aboard the Soyuz-9 spacecraft has been terminated successfully. Studies have also continued in ground-based trainers and simulators to study the psychological capabilities of man in controlling space vehicles, work-rest regimes for the cosmonauts have been worked out, and so on.

All this has led the authors to supplement their previous book with the new data accumulated in the field of space and aviation psychology. The new book required writing individual chapters not related to the questions of space and time perception, and this led to the new title. We have attempted primarily to show the role of the cosmonaut as operator in the man-spacecraft system, integration of man and machine into a unified system, and also the importance of spacecraft crew coordination. The chapters covering questions of space and time perception in space have been supplemented with considerable new experimental data. A major portion of the book is devoted to the biomechanics of man's movements under changed gravity conditions and the problems of retaining the cosmonauts' work capability during extended space flights.

The authors realize quite clearly that the problems considered in the articles presented to the reader here are by no means covered completely and require further development. However, we hope that the present work will give useful information on the psychic activity of man under space conditions and will serve as an impetus for further and more detailed studies of the subject problems.

CHAPTER 1

THE COSMONAUT AS AN OPERATOR IN THE MAN-SPACECRAFT SYSTEM

K. P. Feoktistov, pilot-cosmonaut of the USSR, wrote: "Equipment has already been developed which nearly completely automates the spacecraft monitoring and control processes (otherwise we could not have sent automatic interplanetary probes to Mars and Venus or tested the first spacecraft in unpiloted flights)... There is no question of the possibility of complete and quite reliable automation of all the control processes aboard the spacecraft. But then, what is the role of man in controlling the spacecraft?" /7

The answer to this question is intimately connected with the answer to the following question: why was space exploration started, what is it yielding and what will it yield for the people in the future. In the popular science literature and even in the scientific literature, we often encounter references to the unsatiable thirst of man to know the world surrounding him, the inherent desire of people to discover the secrets of the universe, and so on. This, obviously, is to some degree true. But what is the factor which has led to the thirst for knowledge in this particular field, in the study of outer space? Any attempt to explain the fact of man's "gravitation" into space simply by "idle curiosity" is obviously untenable.

In accordance with the classical views of Marxism-Leninism the appearance of the requirement for studying and conquering outer space can be understood only from the practical requirements, which serve as the basic moving force for the development of theory. The demands of practice, specifically the production requirements, indicate the direction for the development of science and move it ahead.

From the very beginning, the desire for knowledge of outer space was the result of practical needs. The study of astronomy in ancient Egypt, Babylon, China, and India resulted from the requirements of agriculture, animal husbandry, trade, and ocean navigation. Thus, astronomy as a subject which studies phenomena taking place far from the earth served specific terrestrial objectives from the very beginning.

For a long time the knowledge of celestial phenomena /8
obtained with the aid of observations from the earth satisfied to one degree or another the demands of everyday life. But at a definite stage in the development of engineering and science an urgent need developed for extending and generalizing this knowledge.

One of the most immediate and direct factors leading to man going into outer space is undoubtedly the demands of several branches of the national economy and the fundamental sciences. We shall not go into detail here in listing the "demands" coming from many branches of engineering and science which can utilize knowledge of outer space. Considerable literature is now available on the use of the advances in cosmonautics for the organization of radio and television transmission over long and intermediate distances, for the conduct of meteorological, geological, geophysical, astronomical, physical, and many other investigations. However, it is already clear that the scientific information obtained with the aid of artificial satellites and automatic interplanetary probes is fundamentally limited. This is explained first of all by the fact that the automatic devices are capable of yielding information only within the framework of the programs introduced into them ahead of time by man. However, if the automatic device encounters some phenomenon or class of phenomena which were not foreseen by the program, it cannot provide any information on these phenomena to man. And we know that in space and particularly on the planetary bodies there are many different objects, phenomena, and processes which are not yet entirely clear or are completely unknown to science. Hence arises the urgent requirement for creating the conditions for man himself to participate directly in the observations and experiments conducted in space.

Thus, the basic task of man in space is to obtain scientific information by direct observation and conduct scientific experiments. Feoktistov came to this same conclusion.

Scientists from various fields (astronomers, physicists, biologists, meteorologists, and so on) must be brought in for thorough study and investigation of the various phenomena in outer space, and specialists from the various professions (assemblers, electrowelders, construction personnel, and so on) are required to assemble orbital stations and set up and align observatories and laboratories on the planetary bodies. It is obvious that these specialists will be delivered to the orbital stations and planetary laboratories on spacecraft piloted by professional cosmonauts.

While at the present time the cosmonaut is assigned both the task of controlling the spacecraft and its systems and conducting scientific investigations, it is obvious that in the future these functions will be distributed among various individuals. This differentiation has already been noted in the flight of the Voskhod spacecraft piloted by V. M. Komarov with K. P. Feoktistov, a scientist, and B. B. Yegorov, a doctor, as the other crew members. /9

In discussing to some degree the role of man in the scientific and research work involved in the study of space, we should make special mention of the functions of the professional cosmonaut which are associated with control of a spacecraft saturated with automatic equipment.

While in the evolution of aircraft equipment man was from the very first the main element in the system for controlling heavier-than-air vehicles, in the development of cosmonautics the main emphasis from the very beginning was on automated equipment. Even when building the first manned spacecraft (Vostok and Mercury) the designers were faced with a quite limited objective — provide for the possibility of human life under the conditions of outer space and carry out studies to find out how the space flight factors affect man's physiological and psychic functions.

This solution was entirely justified for the first flights, since on the basis of certain ground-based experiments and theoretical arguments many scientists expressed doubt concerning the possibility of living and working under the conditions of outer space. For example, some scientists considered that the loss of weight would lead to psychic disorders which would not only prevent man from working but would make it impossible to live in space. One American investigator wrote: "No one is in a position to predict precisely what the influence of outer space on man will be. Only this is certain — man will be isolated and lonely in space."

Nor can we ignore the fact that foreign developments in outer space were initiated on the background of the "cybernetic boom", when many specialists in this field thought that the presence of man in the system used to control automatic systems is not really necessary and it would soon be possible to do without man in the system entirely. "It was not realized by everyone or immediately," wrote B. F. Lomov, "that attempts to achieve complete automation were not only premature but also unrealistic " (1967, p. 4).

Satellites and automatic interplanetary probes are very complex and consist of several thousand detailed parts and various systems. However, the manned space flight vehicles are still more complex. While during the flight of satellites and automatic probes many of the systems operate periodically, for example /10
the flight trajectory correction engines, on manned spacecraft many of the onboard systems operate all the time. For example, the regeneration system must operate all the time to provide the cosmonauts with oxygen and remove carbon dioxide from the exhaled air. On today's spacecraft these systems are comparatively simple. But, when interplanetary ships are equipped with an ecologically closed cycle with inclusion of plants and animals in the loop, the life support system becomes extremely complex.

No matter how reliable and advanced machines may be, they are still assembled from many elements — units, transmissions, engines, electronic equipment, and so on, which inevitably wear out and not all at the same time. And the more complex any mechanical, electronic, or other system, the greater is the probability of a problem in some part or element of the system.

From this we can conclude that the cosmonauts will be required during flight, in addition to conducting scientific and research tasks, to perform constant observation of the ship's automatically operating systems and in the case of failure of the latter they must take an active part in the system operation, shifting from the monitoring function to the manual regulation function.

During the first American orbital flight, the astronaut John Glenn had to land the ship using the manual mode because of failure of the automatic system. In his report Glenn emphasized that "greater responsibility for control of the spacecraft than was planned can be assigned to man. In many areas the safety of man's return may depend on his actions. Although such situations have not been considered in the Mercury project, the astronaut has not been considered just a passive passenger even in this design. Even where automatic systems are required, their reliability can be increased markedly by the presence of man. The Friendship-7 flight is a good example of this situation. The ship would not have been able to complete three orbits and return to the earth without the presence of a man aboard." An autopilot failure in the Voskhod-2 Soviet spacecraft forced its commander P. I. Belyayev to use manual control.

Concerning the lunar landing of the Apollo-11 spacecraft module, Neil Armstrong radioed to the earth: "We came down right toward a crater the size of a football field, surrounded by huge boulders. It was necessary to switch to manual control to select another spot for the landing."

These and other facts have shown convincingly that, no matter what the degree of automation aboard the spacecraft, man retains the managing and organizing role in its control. The importance of this role will continue to increase with further exploration /11 of outer space. Thus, during the circumlunar flight of the American astronauts aboard the Apollo spacecraft the crew members were assigned the major role in controlling the ship.

The farther the daring space explorers find themselves from our planet and the farther they penetrate into the outer reaches of space, the more often they will come up against unforeseen situations and phenomena which require fast and correct reactions, including situations in the field of spacecraft control. In this case it will not always be possible to obtain the required instructions or timely advice, or consult with the earth. Another problem will be the ever increasing time delay between the moment of transmission of information to the earth and the moment the return information is received from the earth with increase of the distance. For the Moon this delay amounts to about 2.5 seconds, while for Venus the time is about five minutes. And this is without considering the time required to work out the answer to the cosmonaut's question. Possible cases of interruption or loss of communication between the spacecraft and the ground-based flight control centers must also be taken into consideration. It is clear that no cybernetic devices are capable of replacing the creative intellect and intuition of man, which are absolutely necessary in the solution, and particularly in the completely independent and immediate solution, of the problems associated with spacecraft control under unforeseen conditions.

We see from this discussion that we must not contrast the automatic devices with man or man with the automatic devices, but rather find the most rational ways and techniques to integrate man's capabilities with the automatic equipment.

INTEGRATION OF MAN AND MACHINE

> Render unto man the things that are man's and unto the computer the things which are the computer's.
>
> N. Wiener

"One of the great problems which we will inevitably run into in the future is that of interaction between man and machine, the problem of the proper division of functions between the two," wrote Norbert Wiener, godfather of cybernetics, in his last work "God and Golem, Inc." (1966, p. 81). This is not just a problem of the distant future but rather one of today.

The problem of the division of functions between man and machine has arisen most sharply in cosmonautics, since spacecraft are saturated with the most complex automatic and electronic equipment. The proper theoretical and practical solution of this /12
problem will define not only the design of future spacecraft but also the professional preparation of the cosmonauts, the strategy and tactics of future manned spacecraft.

The integration of man and automatic equipment into a unified control system requires profound study of all those complex interactions which are logically created between the man and the automatic equipment during their joint development and requires consideration for the specific nature of both machine and human factors. The optimal resolution of this problem requires skillful utilization in the control systems of the relative advantages of both the man and the machine. In solving these problems, we must keep in mind that the division of functions between man and the automatic equipment is not constant and fixed — it is relative. "Decisions relative to allocation," writes A. Chapanis, "are always made at a definite time and are associated with a given level of development of technical science. It was not so long ago that the question of where to assign the computational operations, to the man or to the machine, was meaningless. Only recently have computers begun to perform these functions. Similarly, today it is meaningless to ask whether to use mechanical sensors to recognize targets; but this question may take on practical importance 20 years from now. The status of electronics is changing so fast that we can be certain that what is impossible today will become possible tomorrow" (1964, p. 100).

In creating any automatic equipment the designer can, by carrying out suitable tests, determine precisely its capabilities and charactersitics for the solution of the tasks posed and find the complete technical description of the equipment. Although the functional characteristics of man at the present time are not subject to as precise a description as are those of the automatic systems, nonetheless, to some degree of approximation we can speak of the relatively stable psychophysiological qualities of man.

The theory and practice of man-machine integration have created concepts which permit examining the functional characteristics of man and machine from a unified viewpoint. Here the decisive role has been played by the science of control — cybernetics — which has formulated the unified principle for the examination of control processes in living organisms and machines.

Naturally, the operation of a machine, by which cybernetics means a system capable of performing actions leading to a definite objective, and the work activity of man are qualitatively different. Man, in transforming nature, carries out consciously formulated tasks, while the machine is only an executor of man's will, a tool of his labor. And the psychophysiological processes taking place in the human organism while he works are also fundamentally different from the processes in automatic systems. Still, there is much in common between the functions performed by man and the machine, which makes it possible to compare certain blocks of automatic systems with the sense organs and operation of the brain centers. /13

This approach to the study of the psychic properties of man from the viewpoint of cybernetics makes it possible for technical specialists to create machines in which certain human functions are simulated. On this subject A. Clarke in his book Profiles of the Future wrote: "All the ideas on thinking machines are inevitably conditioned by and inspired by our knowledge of the human brain — the only thinking device which we have available. No one, naturally, pretends to have a complete understanding of the operation of the brain and there is no hope that such understanding will be achieved in the foreseeable future.... But we know enough about the brain's physical structure to draw a good many conclusions on the limitations inherent in the brain" (1966, p. 264). Thus, in explaining the behavior of man we must start not from the operating principles of electronic and other machines but just the reverse. The machines must be considered as devices in which certain human functions are modeled or copied. This is why engineering psychology in analyzing the man-machine system considers two aspects — engineering and psychological.

Let us examine from these viewpoints what functions man can perform better than the machine as an element in the control system and vice versa.

In order to control a spacecraft man must perceive in a definite fashion his surroundings, interpret the information obtained, and act on the spacecraft control system in accordance with the solution adopted.

Many of the technical instruments intended to detect changes in the surrounding medium and in the objects controlled by operators are considerably inferior to the human sense organs. It has been established by the psychophysiologists that we can sense the odor of artificial musk when its concentration is 0.000000005 gram per cubic meter of air. The following calculations of K. K. Platonov give a good idea of the "resolving" power of the human sense of smell. Lake Teletskiy is 78 km long, average width 3 km, and typical depth 20 meters. The water volume in the lake is about $46 \cdot 10^9$ m^3. In order to obtain the concentration required for sensing the odor of musk in the same volume of air, we need only dissolve in the lake about a cup (230 grams) of this crystalline substance.

The human eye is a still more sensitive device, which has /14
been created by nature. Man can differentiate nearly half a million colors and tones. In clear air on a dark night we can see a candle flame at a distance of 27 km. A light flash lasting only 0.0003 second is clearly perceived by the eye.

With the aid of his sense organs man can not only perceive various stimuli over a wide range, but can also evaluate precisely signals which vary in some way or another over quite wide limits.

For example, when reading man can perceive correctly letters which vary in size, inclination, shape, and so on. In contrast, the "reading" machines now being designed can "perceive" only a strictly standardized format.

But man has even more advantages. He can perceive and interpret "amorphous" information, which no machine is capable of perceiving, and draw a corresponding conclusion on this basis. Concerning this, Norbert Wiener wrote: "We must consider that the brain in comparison with modern computers has definite advantages associated with its tremendous functional range, which is unbelievably larger than we would expect in view of its physical size.

The principal advantage is apparently the ability of the brain to work with imprecisely defined concepts. In such cases the computers, at least at the present time, are nearly incapable of self-programming. However, our brain readily perceives poems, novels, and pictures whose content any computer would be forced to discard as something amorphous" (1966, p. 82).

Studies have shown that a certain time is required for passage of a nerve stimulus from the sense organs to the brain, processing of the information, and for the response motor reaction. An event which took place at the end of the 18th century and initiated the study of psychomotor reactions is of some interest.

In 1795 Maskelyne, the director of the Greenwich Observatory, discharged the astronomer Kinnebrook for being half a second late in noting star passages through the meridian. Maskelyne established Kinnebrook's observation errors by comparison with his own observations, which he considered to be entirely correct.

However, 30 years after this event the German astronomer Bessel found that all observers, including Maskelyne, note the time of star passage through the meridian imprecisely. It was found that each observer has his own average delay time. From that date on, this has been taken into consideration in astronomical studies in the form of a coefficient called the "personal equation."

The motor reaction delay time, i.e., the time from the moment a signal appears to the moment of initiation of the motor response to the signal, was first measured by Helmholtz in 1850. This time was different for different individuals (varying from 0.1 to 0.2 second). However, in the case of a slight complication of the experiment, for example when the subject is required to press a button in response to the flashing of a light of definite color from among several such lights, the motor reaction time increases significantly — to 0.5 second or more.

The inadequate response speed of the psychophysiological reaction of the human being becomes particularly noticeable in the control of jet airplanes. Thus, at a flight speed equal to twice the speed of sound there is a "blind" distance ahead of the airplane, which is not perceived by the pilot. Objects ahead which appear to the pilot to be 100 meters away are actually already alongside. If two pilots approach one another, each at this speed, they will not see one another at all at distances of less than 200 meters.

Extensive experience in aviation and the corresponding experimental data indicate that about 1.5 - 2 seconds are required in flying a jet airplane to evaluate an ordinary situation. During this time an orbital spacecraft will cover about 16 km. At first glance it appears that at such a speed, to say nothing of higher speeds, the cosmonauts cannot react at all to many events taking place in outer space. But this is not the case at all.

This is what Gagarin had to say about the perception of the outside world during the first space flight: "From a height of 300 km the sunlit surface of the earth could be seen very well. Observing the surface of the earth, I saw clouds and their slight shadows which lay on the fields, forests, and seas. The water surface appeared dark with shiny spots. I could distinguish clearly the continental shores, islands, large rivers, major water reservoirs, and terrain folds. When I flew above the Soviet lands the square rectangles of the collective farms were clearly identifiable. I had previously been able to climb to an altitude of no more than 15,000 meters in airplanes. Naturally, the visibility is not as good from a satellite spacecraft as from an airplane but things could still be seen clearly. I was really surprised that details of the earth's surface were so easily visible from the satellite altitude. Although the ship was traveling at a speed of 28,000 km/hr, all the objects on the earth's surface seemed to float slowly by in my field of view, which was limited by the spacecraft window.

The fact that man can see clearly objects on the earth's surface, stars, and other space objects even at space speeds is explained as follows. If we look out the window of a train in motion at the embankment we see continuous merging lines. If we /16 gradually shift our view farther from the window we can differentiate three zones, merging, flickering, and clear vision of individual objects. The boundary of the zone between flickering and merging aids the experienced pilot in determining the distance to the ground when landing an airplane.

The closer above the earth's surface the cosmonaut flies, the less possibility he has of reacting to the objects which he sees. However, from an altitude of 200 - 400 km, the earth viewed from the spacecraft window seems to be slowly floating by. In interplanetary flight the cosmonaut will not have any sensation of speed at all. A monotonous pattern will be presented to him. In one window he will see bright unflickering stars, in the other he will see the blinding disk of the unsetting sun. In spite of the movement, at space speeds everything will be perceived as frozen in place and stationary. Thus, the cosmonaut will even have "excess" time as the spacecraft travels further away from the celestial bodies. Conversely, when approaching any celestial body or the earth a time "shortage" will appear. In these cases automatic equipment will come to the aid of man.

With the aid of radar and optical techniques aboard the spacecraft, we can essentially "extend" man's sense organs and thereby increase his perception radius. The creation of special equipment which makes it possible to receive signals from the surrounding medium, process these signals rapidly, and put out the corresponding commands to the rocket's actuating mechanisms provides the possibility for reacting to a change of situation, say the appearance of a meteorite, tens or even hundreds of times faster than man can react.

Here is another example. Maneuvering of a spacecraft in the rendezvous and docking process differs markedly from the maneuvering of flight vehicles in the atmosphere. For example, in order to catch up with another airplane the pilot must both increase his airplane's speed and maneuver in space. When accomplishing a maneuver, say a change of altitude, the pilot changes the wing angle of attack so that the wing lift force becomes greater than in horizontal flight. These aerodynamic control relationships no longer act under the conditions of space flight. Thus, if a spacecraft is subjected to only a reactive force in order to catch up with another spacecraft which is in the same orbit but somewhat ahead, this accelerating force will alter not only the flight velocity, but also the orbit parameter. The ship goes into a higher orbit, or in the case when its velocity decreases it goes into a lower orbit.

Since the human being is not capable of figuring out in short time intervals what command signals must be transmitted to the spacecraft engines in order to perform such maneuvers, a computer is used to assist him. Such computers were used on /17
the Gemini spacecraft to carry out orbital rendezvous and manual docking with the Agena rocket booster. Computers were used in the Apollo circumlunar flight to make flight trajectory corrections and also to carry out maneuvers in lunar orbit.

The cosmonaut's role increases particularly in the last segment of the docking maneuver, when he engages manual control. The spacecraft velocity must not exceed a few meters per second relative to the docking target. The closer one ship approaches the other, the lower the relative velocity must be in order to provide shock-free engagement, but at the same time the velocity must be sufficient to actuate the docking locks. Obviously, the ship and target must be suitably oriented relative to the docking fittings.

The docking of two spacecraft was first accomplished in the Soviet Union in 1969. V. Shatalov had the following to say about this maneuver: "After the successful launch of the Soyuz-5 vehicle into orbit, the second stage of the flight was initiated — rendezvous and docking in orbit. The Soyuz-4 and Soyuz-5 ships performed several rendezvous maneuvers under manual control from a distance of more than 1000 km. When the distance was reduced to a few kilometers, the automatic rendezvous system came into operation. The rendezvous correction engine on the Soyuz-4 ship was activated several times by command from this system. This provided a gradual approach of the two ships to one another with a speed which depended on the distance. I monitored the automatic rendezvous on the instruments and visually through the optical sight and a television set. During the rendezvous the Soyuz-5 spacecraft was oriented with its docking fitting pointing at Soyuz-4.

"At a distance of 100 meters Boris Volynov and I switched over to manual control of the ships.

"We controlled the ships to maintain the required relative orientation. I varied the rate of approach of the two ships as a function of the distance between them.

"Over the African coast, at a distance of 7000 - 8000 km from the borders of the Soviet Union, we approached to within about 40 meters of one another and held this distance. At this distance Volynov and I performed several maneuvers, during which we changed the relative position of the ships and photographed one another. Then we continued the docking maneuver and completed the link-up in the zone of direct television communication with the earth.

"In order to avoid rough impact the relative approach velocity at the moment of contact was reduced to a few tens of centimeters per second." /18

In contrast with an automatic system, man is capable of receiving information simultaneously from various sense organs and combining this information into an integrated image. Man has a tremendous memory capacity, i.e., he has the capability of storing information which, expressed in the language of cybernetics, requires "minimal programming".

Only man is capable of abstracting, generalizing, and forming concepts. This capability, together with his memory, gives him the possibility of recreating images and events which took place in the past and applying them to a given concrete situation, and also makes it possible to go beyond the limits of the present and mentally anticipate events, foresee the future.

These psychological qualities are particularly important in so-called problem situations, when man, in making a decision, must radidly analyze an unforeseen situation which develops and find ways out of this situation. "Problem situations" can arise as a result of various factors. Sometimes they arise as a result of failure of an automatic system or under the influence on the object being controlled of unexpected and unforeseen external inputs.

The studies of D. N. Zavalishina and V. N. Pushkin have shown that in the process of solving problem tasks, the operator must utilize a prepared program, i.e., a definite action algorithm which is known to him ahead of time. However, in atypical cases the intellectual activity of the operator takes on a creative, heuristic nature. In this case, operative reasoning, associated not with the use of stereotypical concepts and skills, but rather with seeking new paths and solutions for the developing problem situation, will play the dominant role.

Studies of Teplov, Lomov, and others have shown that in this form of psychic activity, pictorial and verbalized reasoning acts in a unified fashion, and this is what provides a concrete reflection of the problem situation. On the basis of this image the operator works out a strategy for his behavior and by his actions begins to act on the controlled object. To date none of the modern cybernetic machines has the capability of operative reasoning, which makes it possible to work out an action strategy in problem situations.

Man is also characterized by great flexibility in the role of executor of commands. Using one and the same motor apparatus, he is capable of performing quite different actions. In contrast with the machine, man adapts well to control and can improve this quality almost without limit by means of training, /19 while the degree of adaptation of the automatic system is embedded in its structure, and in general can be increased only slightly at the present time. Man, however, with some training, can carry out regulating functions in many control systems, no matter how different their functional and structural diagrams, with equal success. He is capable of comparatively easily and quickly changing the programs which are to be used in performing the regulation. He is also capable in case of certain failures of shifting from one technique for performing his functions in the control system to a different technique. The machine, however, in such situations ceases working or makes serious errors. The following argument of Thomson indicates clearly how far the capabilities of an automated system still are from man's capabilities: "The hand of a monkey, although not as advanced as our hand, is an amazing tool, particularly together with the animal's eye and brain. Just think how much electrical power would be required to create a machine capable, for example, of picking oranges from a tree without damaging the tree itself. We would think we had handled the task well if we were able to install such a machine on a large truck, and its operation would require considerable expenditure of energy. The monkey performs the same operation while weighing only about 40 pounds and requiring a pound of nuts per day" (1958, p. 138).

It is true that man is subject to fatigue and boredom, which leads to decrease of the quality of his work in controlling the spacecraft, and also such psychic conditions as fear, fright, panic, and so on can lead to an emergency situation and his death. Machines are free of these problems. As a rule, machines have high stability with respect to the ambient medium and its changes. Still, the use of man as an operator in automated systems is not only advisable but even necessary, as has been confirmed by special experiments.

Thus, American investigators have made a comparison of the operational reliability of completely automated onboard spacecraft systems (with double, triple, four-fold, and five-fold duplication), and also systems including an operator. Initially, the operation of all five systems was equally reliable. But by the fourth day of a simulated flight there was a difference between the reliability curves. At the end of the 14-day period the reliability of the systems with two-, three-, and four-fold duplication could not be considered satisfactory, while the reliability of the system with five-fold duplication was not sufficiently high. During the same time the operating reliability of the system which included an operator changed very little and was higher than that of the other systems. In addition, its weight was less than that of the other systems, which is very significant for spacecraft with their severe weight /20
limitations. From this analysis it was concluded that the use of the cosmonaut as an operator is most favorable, effective, and at the present level of hardware development is a progressive step (Figure 1).

Thus, man with the aid of various automatic devices is capable of injecting a spacecraft into a given orbit, correcting the flight trajectory to the moon or other planets, selecting the most suitable area for landing on a celestial body, and so on, more precisely and reliably than can the automatic systems alone. This leads to the need for optimal integration of the cosmonaut and automatic systems, combining them into a unified control system.

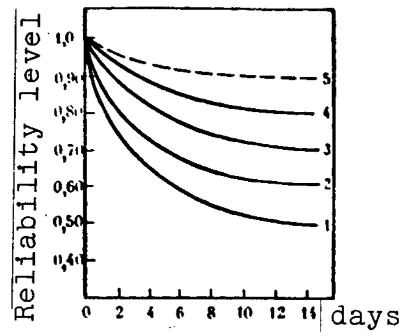


Figure 1. Reliability of fully automated spacecraft control system with two-, three-, four-, and five-fold duplication (1 - 4) and including man (5)

The problems in creating an optimal system which includes both man and automatic equipment lie in ensuring the maximal possible effectiveness of the integrated system, commensurate with the limitations which are inherent to both the hardware and the man. In the case of this integration of man and machine, under certain conditions the machine must be monitored and controlled by the man, and man's operations must be replaced where the machine has the better capabilities. The reliability of the spacecraft control system increases considerably in the case of this rational combination of the capabilities of man and machine.

Here is an example which shows graphically the correctness of this approach. It has been calculated that the reliability of an automatic control system designed for flight around the moon and return to earth is 22%. With the participation of man it increases to 70%. However, if man is presented the possibility of correcting various faults in the different spacecraft systems, the reliability increases to 93% or more. These calculations have been completely verified during the lunar flights of the American astronauts.

The American Apollo-13 spacecraft was launched from Cape Kennedy on 11 April 1970 at 22:13 Moscow time. The crew consisted of the ship commander James Lovell, lunar module pilot Fred Hayes, and command module pilot John Swigart. The flight was planned to last 10 days and land two of the astronauts on the moon. /21

However, problems arose on board during the very first minutes of the Apollo-13 flight. During the boost phase the center engine of the second booster stage shut down two minutes earlier than planned. Vibration was noted during firing of the second and third stage engines. While in earth orbit, the automatic system failed to complete hard docking of the crew capsule and the lunar module. The astronauts closed two of the locks manually.

On April 13, when the spacecraft had already traveled more than half the distance to the moon, the astronauts switched the spacecraft into a so-called hybrid trajectory in order to inject the ship into a selenocentric orbit with the least energy expenditure.

On April 14 at 06:25 in the morning an emergency signal awoke the astronauts. A liquid oxygen bottle had burst as a result of pressure increase, and the spacecraft was 328,000 km from the earth. A second oxygen bottle was also damaged by fragments. Since the oxygen from these bottles was used to operate the fuel cell batteries which constituted the main source of electric power for the command module and the life support system, the crew immediately found themselves in a critical position.

From this moment there was no longer any thought of completing the planned program. From now till the end of the flight all the knowledge and experience of the astronauts and the ground support specialists were directed to save the crew and return the ship to earth. At the Flight Control Center in Houston, the system specialists and experienced astronauts utilized computers and simulators to find the best regimes for conserving electric power and oxygen.

The lunar module became their "lifeboat", as the astronauts called it, in the ocean of space. Two members of the crew transferred into the lunar module through the interconnecting tunnel and activated the power system and life support system. The hatches in the interconnecting tunnel remained open so that oxygen could feed into the crew capsule, where the third astronaut remained.

It appeared that the immediate threat to the crew had been eliminated. However, it was soon found that the life support system of the lunar module could not cope with carbon dioxide absorption. Using their pressure suit hoses, the astronauts connected the lunar module system to the lithium hydroxide cartridge in the crew compartment.

After getting out of one difficult situation the crew immediately encountered another. The lack of electric power immediately affected the operation of the temperature control /22 system. The temperature in the crew compartment fell to +5°.

All this took place when Apollo-13 was approaching the moon along the "hybrid trajectory". Therefore, the most urgent problem facing the crew and the flight director was to transition the ship to a free return trajectory. This could be done only with the aid of the lunar module landing stage engines. However, a reduction of the pressure in the helium tank used in the expulsion system for feeding fuel to this engine had been noted during the launch and during flight.

However, at about 12:00 on April 14 they managed to make a trajectory correction and the spacecraft, after circling the moon at a distance of 250 km, started back for the earth.

During the moon-earth segment the crew made two more trajectory corrections to ensure splashdown in the Pacific Ocean.

Shortly before the landing, the astronauts left the lunar module and entered the crew compartment. The final operations in separating the engine section and the lunar module went normally. The astronauts noted that the engine section had considerable damage — the skin was torn along the entire length. "Complete chaos," they radioed to the flight control center.

After reducing the orbital speed in the atmosphere, the crew capsule was landed using parachutes. This occurred at 21:08 on April 17 in the Pacific Ocean. This was the end of the dramatic Apollo-13 flight.

This flight demonstrated convincingly the role of the astronauts in avoiding the consequences of an accident, their bravery, and endurance.

We should emphasize here that the most rational integration of man into the unified man-spacecraft system can be achieved only when the psychophysiological characteristics of the operator and the technical characteristics of the machine are considered in the spacecraft design.

THE COSMONAUT AS OPERATOR IN THE MAN-SPACECRAFT SYSTEM

> The individual is always primary; the individual must be as strong as a rock for everything is based on him.
>
> I. S. Turgenev

We have established that the professional activity of the cosmonaut is a variety of operator activity with the use of highly automated equipment. The cosmonaut is included in the man-spacecraft-space system as a control element. /23

Common to the activity of operators controlling any vehicle, whether this be a railroad dispatcher or flight dispatcher, pilot or electric power station operator, cosmonaut or tram conductor, is that all changes of the controlled vehicle are determined with the aid of sensors. The signals from the sensors are transformed and transmitted to instruments which the operator observes. He perceives the instrument indications, analyzes (decodes) them, makes a decision, takes the corresponding action, which may be very simple (pushing a button, for example) or more complex. The signal which occurs as a result of the operator's action is transformed and transmitted to the controlled vehicle, altering its state. The new state of the vehicle is accompanied by change of the instrument indications, which informs the operator of the results of his action. This, in turn, requires new actions from the operator, and so on. In general terms, this is how a closed regulation system looks in which the operator, having direct and feedback connections with the controlled vehicle, appears in the role of a very important and most responsible element of the system, namely, the regulator. A block diagram of a man-machine system is shown in Figure 2.

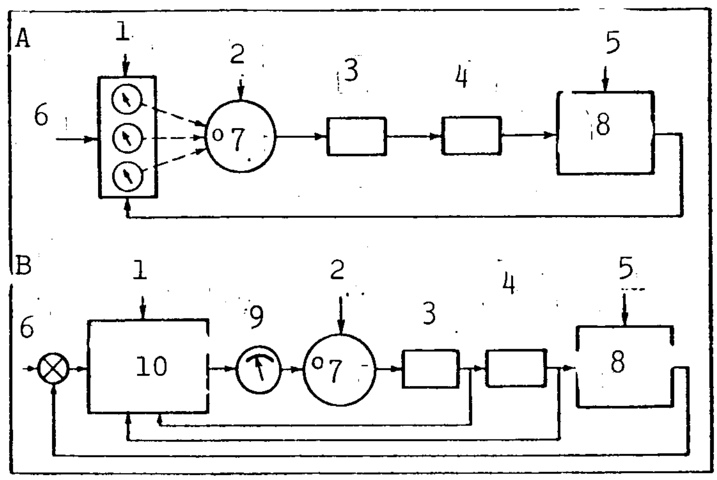


Figure 2. Block diagram of semiautomatic spacecraft control

A — pursuit tracking; B — compensation tracking /24

1 — external conditons; 2 — external conditions of ambient medium; 3 — control organs; 4 — actuators; 5 — disturbances and noise; 6 — indicators; 7 — operator; 8 — controlled vehicle; 9 — director instrument; 10 — computing and correcting devices

Lomov notes three primary tendencies characterizing the change of man's activity when operating in automated systems. First, because of the growth of mechanization and automation, man is faced with the problem of simultaneous control of an ever increasing number of factors (parameters). This complicates the analysis and evaluation of the vehicle conditions and therefore the programming operation. Second, man is increasingly further removed from the objects being controlled. Under remote control conditions he may not even perceive their conditions directly. Between the man's sensing organs and the controlled object, there is "interposed" a whole system of technical devices to transmit the required information, which in this case is usually encoded; now a new problem arises — decoding, which did not exist in the case of direct perception of the course of the controlled process. The operator's input to this process is also mediated by a system of technical devices, which alters the requirements on the working movements. Finally, under the conditions of today's technology, there is a considerable increase of the requirements on the worker's speed of action as a result of increased speeds of the processes being controlled.

In evaluating the role of man in control systems we must consider two intimately interrelated factors. On the one hand, the advances of technology increase the possibility for transferring many very complex functions from man to machine: there is a partial replacement of man by the "machine elements" of the system. In this connection there is a broadening of the range of problems which the system is capable of solving. On the other hand, the larger the number of machines involved in the control process and the broader the range of problems, the greater is the need for integration of their operation. And this means that the relative role of man in the control systems increases and becomes more critical.

We have noted above that one of the important functions of the operator in the man-machine system is to obtain information on many processes in the controlled vehicle and in the outside medium, which affects the controlled vehicle. The data coming along the communications channels from the controlled objects and characterizing the state of the external medium and the state of the control system itself, and the representation of these data on the particular devices (indicators, panels, screens, signalling devices, instruments, and so on) form what Panov and Zinchenko have termed the "information model of these objects".

The information model is the direct source of information for the operator and is what he uses in making decisions which ensure proper operation of the system and performance of the tasks imposed on it. In introducing the model concept into engineering psychology, Panov and Zinchenko have given it a different meaning in comparison with Crossman, Welford, and Chapanis, who have also used this concept. The latter speak of "conceptual models", i.e., models which are formed by the operators as a result of receiving and processing information on the controlled objects. Panov and Zinchenko emphasize that the conceptual /25 models are derivatives of the information models, and the determination of the requirements on the information models as elements of the control system is more essential in the initial stages.

The first manned spacecraft was Vostok. In this vehicle the information on systems operation is presented in the field of view of the cosmonaut on a panel containing instruments indicating the humidity, temperature, gas composition of the air, number of orbits completed, clock, and so on (Figure 3).

Also located on the panel are signaling systems — lettered legends which illuminate as commands are transmitted, when problems arise in the ship's systems, and so on. The indicator showing the ship's position and the landing area is most prominent among all the instruments. This instrument consists of a sphere which rotates about two axes at a rate corresponding to the earth's rotation rate and the angular velocity of the spacecraft in the orbital plane relative to our planet. This instrument provides the cosmonaut with information on his location at any time and permits him to determine the landing spot when activating the braking engine at a given moment of time.

A

B

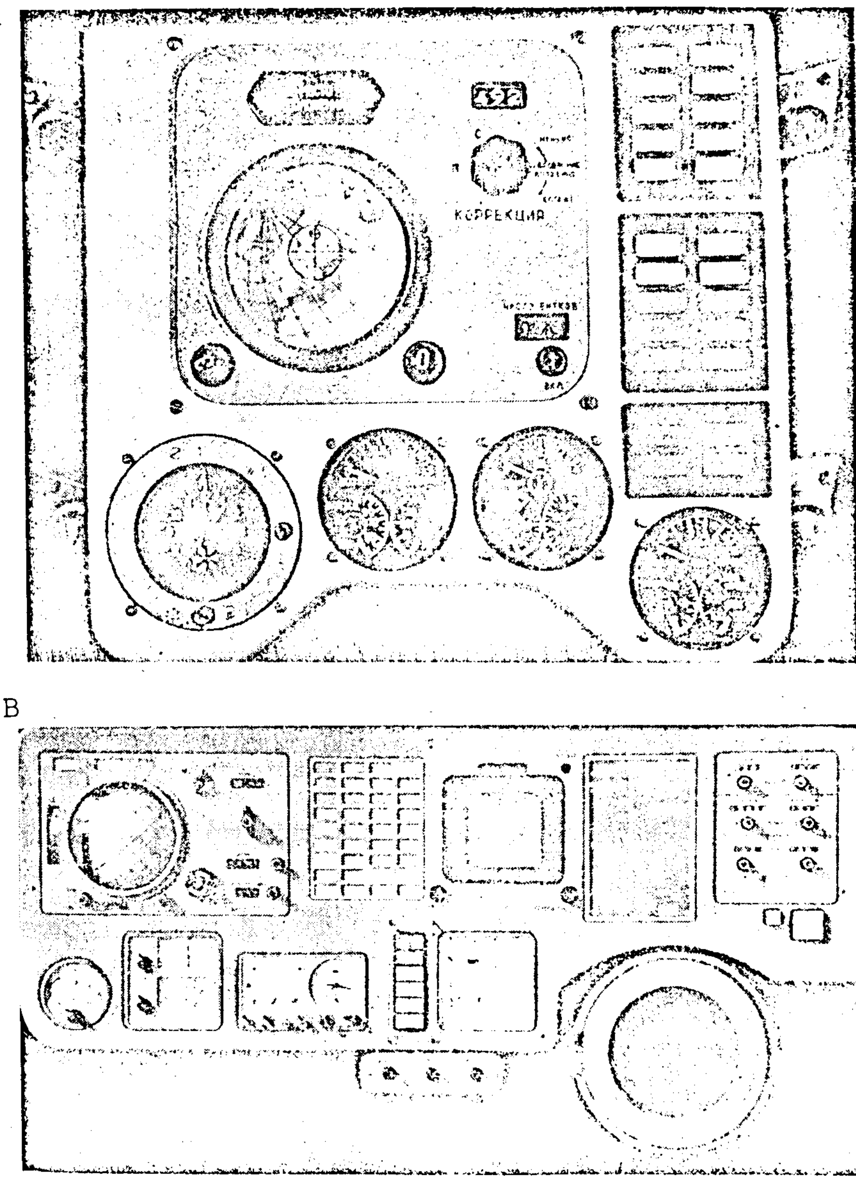


Figure 3. Instrument panels of Vostok (A)
and Soyuz (B) spacecraft

The Voskhod and Voskhod-2 spacecraft solved more complex problems in the course of their flights in comparison with the ships of the Vostok class. Thus, the first spacewalk took place from Voskhod-2. Successful completion of this experiment required additional information. Instruments were provided on the panel to indicate the pressure in the airlock, opening and closing of the hatches, and the pulse rate and respiration of the exiting cosmonaut.

A new class of spacecraft called Soyuz was created in the Soviet union to carry out planned, step-by-step exploration of outer space. While the Vostok and Voskhod ships were designed to perform a quite definite range of scientific, engineering, and primarily experimental research tasks, the new Soyuz spacecraft has a multipurpose mission.

The presence of two compartments — the cosmonaut capsule (reentry section) and the orbital module — provides more living space for the cosmonauts to work and rest in. The possibility of extensive maneuvering in orbit with the aid of automatic and manual systems makes it possible to join two ships in orbit and replace the crews of large orbital stations. The possibility for the cosmonauts to exit into outside space permits man to participate directly in the assembly of orbital station sections /26
launched into an assembly orbit. This is far from a complete listing of the tasks which can be carried out in accordance with the Soyuz program.

The increased complication of the tasks which can be undertaken by the Soyuz ships has led to increase of the number of instruments. This is particularly clearly seen in comparing the instrument panels of the Vostok (see Figure 3) and Soyuz ships. In Soyuz, instrument panels are provided not only in the cosmonaut module, which is the central control station for the ship, but also in the orbital (living) section of the spacecraft.

Thus, in the course of the space vehicle development, we see a clear tendency toward increase of the number of instruments from one class of ship to another. There is no doubt that on the future spacecraft, and particularly on the interplanetary ships, the number of instruments presenting information to the operator will increase progressively.

The main difficulty in the case of indirect control of the ship through instruments lies in the fact that the operator must not only rapidly and correctly "read", i.e., correctly determine the indications of the instruments, but must also rapidly (sometimes nearly lightning-like) analyze these data, mentally picturing the interconnection between the instrument indications and actual reality. This means that he must, on the basis of the information model (instrument indications), create in his mind a conceptual model of actual reality. In order to transform the indications of the individual instruments into an inner picture, for example a flight trajectory, the cosmonaut must perform a large number of complex information transformations. First he must analyze (decode) the instrument indications, and only then synthesize them into an integrated image of the situation. We shall go into these processes in more detail in the chapter on "Orientation of Man in Outer Space". Here we simply note that the possibility of interpreting the information presented to the operator with the aid of the information model requires that the psychophysiological capabilities of the human operator be considered in creating this model.

Engineering psychology is carrying out a wide range of studies on the rate and precision of instrument indication readout as a function of scale shape, size, and so on. Although this problem is considered relatively simple in engineering psychology, we consider it advisable to present an example from flight experience which shows that even here everything must be worked out and thought out to the very smallest details in order to completely exclude various eventualities.

During a night flight, an airplane was approaching the field after completing a mission. Engineer-colonel M. Kotik reported that the flight controller transmitted the following message to the airplane: barometric pressure 753 mm, cross the marker at an altitude of 1500 m. /28

The pilot pushed the stick forward and throttled the engines back. The airplane started down and the crew got ready for landing. But then something unforeseen happened. The pilot crossed the inner radio marker at an altitude other than the one he was instructed to use. There were other airplanes at this altitude. The error was so serious that the flight controller had to intervene immediately. Only his quick and decisive actions prevented an in-flight collision.

In analyzing this case it was found that during the landing approach the pilot misread the indications of the barometric altimeter. He read the instrument indication of 1100 m as 100 m.

The barometric altimeter on this type of airplane had two pointers. At an altitude of about 1100 m its large pointer, which indicates hundreds of meters, covered the small pointer, which indicates the altitude in kilometers. In this case the pilot saw on the altimeter scale only the single large pointer, located near the 100 m division, and read the flight altitude from this pointer.

The specialists in the field of engineering psychology posed the question of whether or not it is possible to facilitate the problem of instrument readout by the operator and in place of the individual partial indications (or along with them) show graphically the attitude of the controlled vehicle in space. Satisfaction of these requirements ensures, other conditions being the same, maximal speed and reliability of information processing by the operator with minimal strain on him. Following this idea, the engineers along with the psychologists developed a new submarine control panel.

The desired direction of submarine travel is represented on a cathode ray tube screen in the form of a light path extending toward the horizon. The strip is divided by dark transverse bands which appear to approach the helmsman. The helmsman feels as if he were guiding the sub along a corridor; if the sub deviates from the desired course or desired depth, the impression is created that the sub is about to run into the roof or wall of the corridor. Speed change is sensed by change of the rate of "approach" of the bands. We see from this description that here the information is coded so that its perception yields nearly a graphical picture of the behavior of the controlled vehicle (submarine).

Such instruments have been called contact analogs, which yield a "pictorial" representation of the situation and cause an effect of reality. An example of their use in spacecraft is the "Globus" which we mentioned above. But the information from such instruments is qualitative and must often be supplemented with quantitative data coming from conventional indicators. /29

Zinchenko points out that in order to increase the information processing rate it is necessary to study the composition of the operations with the aid of which the information model is transformed into the conceptual model, and also the time for performing each of these operations. In order to create the optimal conditions for expeditious and precise control, we must make the content of the information and conceptual models as similar as possible and thereby reduce the number of operations necessary for creating the conceptual model.

We note that the difficulties are not limited to the complexity of indirect (i.e., through indicators and instruments) reception of information on the external situation; the difficulties are also often associated with rapid transitions from complex indirect orientation in space on the basis of the instruments to the simpler orientation accomplished visually.

The abrupt transition from the perception of the limited information contained in the "information model" to the excess information obtained as a result of visual perception of the surroundings (for example, as an airplane breaks out of the clouds during flight under instrument conditions) in many cases leads to peculiar neurotic disturbances of the higher nervous activity. These disturbances are close to the "brief breaks of higher nervous activity" in the case of neurasthenia, described by N. S. Davidenkov, and are characterized by paroxysmal onset, interruptions in thinking, followed by an emotional reaction of the fright type with vegetative syndrome.

A characteristic example is the singular state of consciousness which developed in flight with 33-year-old pilot L during flight in instrument conditions (observation by O. N. Kuznetsov).

After performing a mission at an altitude of 6000 meters, above the clouds, the pilot returned to the airport area and

initiated a letdown through the clouds using the blind landing system. The airplane entered the clouds, broke out below the clouds, and then suddenly zoomed back up into the clouds to an altitude of 400 meters, after which it again descended, and after normal pattern under the clouds made a normal landing. To the flight commander's question about the reason for the strange violation of the flight pattern the pilot said: "It seemed as if my thoughts just stopped. I don't remember what I did . . . the last thing I recall is that the instrument indications were normal. . . it's as if I lost consciousness but I really didn't." This condition occurred as the airplane broke out of the clouds and was transient. The pilot continued to fly the airplane during this period. After landing it was noted that his skin was pale, he was sweating and in a depressed state. In the hospital he expressed several neurotic complaints. An objective /30
investigation showed vegetative instability, animation of the tendon reflexes (accompanied by general twitching), tremor of the fingers and eyelids in the Romberg posture. Emotional instability, irritability, and poor sleep were noted. Talk of what had happened was very disturbing. No epileptoid activity was noted on the electroencephalogram. Pressure chamber tests showed good tolerance to hypoxia. His timing sense and the fact that he flew the airplane eliminated the hypothesis of any complete loss of consciousness of an epileptic nature.

The neurotic disruption of the higher nervous activity experienced by pilot L occurred when the "excess" information from ground objects was combined with the limited information flow provided by the instruments. The pilot must now not only interpret correctly the instrument indications, but also rapidly synthesize the new information with that received previously into an integrated image. And this requires a high level of conditioning and self-control.

Similar difficulties in the functioning of an operator can also be caused by the "behavior" of automated equipment. On the basis of studies of the fundamental characteristics of automatic processes, i.e., processes taking place in closed loops, the possibility of spontaneous deviations in their activity of a random nature has been established. Sometimes a small external disturbance or impulse is enough to cause the appearance of an unexpected, seemingly "motiveless" deviation after some time in the operation of the automatic system. These deviations, which arise "by themselves", in many cases may lead to the development of neuroses in the operators. An example of a neurotic disruption in the case of unusual "behavior" of defective equipment is the following case, described by F. D. Grobov.

During repeated simulated bombing flights, the "blind bombing" instrument used by navigator P repeatedly failed. After operating quite properly on the ground, this instrument would fail at a definite altitude and prevent completion of the mission. This situation was accompanied by corresponding reactions of tension, irritation, and annoyance. But a particularly unpleasant aspect was the fact that upon descent to a definite altitude and return to the airport the instrument automatically began to work again, and when checked on the ground this put the navigator in a very awkward position. Later on, after he had photographed the instrument at the instant of failure in flight, i.e., "caught it red-handed," the instrument failure was demonstrated, and it was shown that the navigator was not at fault. However, in the course of these events the navigator's behavior seemed so unusual to the doctors that he was put in the hospital, where he was twice subjected to psychiatric examination. As a result of the studies the navigator was found to be in good health and approved for flight without any limitations. However, the conclusion was delayed, and this class I navigator failed to perform /31 a mission, even with instruments in good condition, and brought unreleased bombs back to the field. He had to be transferred to transport aviation duties.

This situation showed very clearly the interrelations between man and an instrument which demonstrated, figuratively speaking, "insidious and crafty characteristics". This situation demonstrates the specific psychological difficulties in working with instruments which have not simply limitations or defects, but rather inadequate stability of their "behavior". Inattention to the interactions between man and instruments may lead to undesirable consequences in the performance of the operators of future spacecraft. This is particularly so because of the fact that the interplanetary spacecraft will be loaded down with electronic self-adaptive systems, i.e., systems, which after receiving the information, will themselves seek out the optimal operating regime with account for the varying external and internal conditions. Such systems do not have rigid programs which are specified once and for all. Consequently, there is a good possibility that the electronic automatic systems will begin to present various surprises.

The cosmonauts must be familiar with the possible deviations in the operation of the instruments, but at the same time they must have faith in the instruments. Neurotic disorders may arise in cases where the operator no longer believes the instruments at all.

The development of neuroses in operators who do not have faith in the automatic systems can be illustrated by the following observation of F. D. Gorbov.

Navigator Z, an experienced specialist, was sent to the hospital for extended observation because of his neurotic condition. When admitted he showed irritability, emotional instability, and inability to sleep. Questioning disclosed that the patient became very fatigued during flight, and it was particularly difficult for him to perform the practice bombing mission, which he had previously enjoyed. It was also found that he had previously received commendations for practice bombing on airplanes not equipped with autopilots. He had reacted quite negatively to the introduction of bombing with the autopilot engaged, since he felt autopilots were not sufficiently reliable. For some time he avoided using the autopilots, then he, like all the other navigators, was forced to carry out bombing using the autopilot. He then began to feel tension building up, fatigue, complained of headaches and irritability. However, he did not refuse to fly and did use the autopilot.

In the initial conversations with the patient in the hospital, there was no mention of the fact that his condition was associated with the difficulties he had encountered with the new /32
bombing technique. It was only from the extreme irritability and the unusual emotional coloration with which the patient spoke of the autopilot that it was possible to identify the situation bothering him. The patient himself was amazed when it was found that he, the "opponent of the autopilot", used the autopilot more than others, even engaging it prematurely. In his behavior, he was reminiscent of the artisan who is assigned an an undesirable assistant. At first the artisan attempts to avoid the assistant but then, seeing that this is to no avail, walks away, slams the door, and leaves the whole business to the assistant.

Naturally, we don't claim that this is a complete discussion and analysis of the questions of information perception with the aid of instruments and processing of the information into a mental image. Here we have simply tried to show how complex this problem is and how seriously it must be approached in order to ensure highly efficient operation of the man-spacecraft system and prevent the development of various neurotic disturbances in the cosmonauts during long-duration flights away from the earth.

The cosmonaut utilizes the pilot's panel to make inputs to the spacecraft and its systems. The pilot's panel of the Vostok spacecraft includes rotary knobs and selector switches which control the porthole shutters and filters, the radiotelephone system, and the temperature in the cabin. Also located on the panel is the interlock for activating manual control and the retro engine.

The Vostok manual orientation systems consisted of the Vzor optical orientator, the control stick which provided change of the ship's motion around three axes — heading, pitch and roll, angular velocity sensors, and other components (Figure 4). The Vzor device consists of two annular mirror-reflectors, light filters, and a glass with a grid. Rays coming from the horizon strike the first reflector, pass through the porthole glass to the second reflector, which directs them through the glass with the grid into the eye of the cosmonaut. If the spacecraft is oriented correctly relative to the vertical, the horizon appears in front of the cosmonaut in the form of a ring. Through the central part of the Vzor instrument he views the area of the earth's surface below him. The position of the ship's longitudinal axis with respect to the direction of flight is determined from the "movement" of the earth's surface in the orientator field of view.

If there is a deviation from the vertical or if the ship's longitudinal axis deviates from the direction of flight, the cosmonaut uses the control stick to send commands to the input of the angular velocity sensors. The latter generate signals which are transmitted to the orientation reaction engines and activate them. As a result the ship begins to rotate. As soon as its rate reaches the desired value, the engine is turned off and rotation continued by inertia. When the ship reaches a definite attitude the cosmonaut releases the stick. This leads to the appearance of a control signal which actuates the reaction engine to reduce the rate of rotation. When the rate decreases to the desired value the engine is turned off. From the psycho-physical viewpoint the process of manual control of the angular attitude of the ship differs considerably from the analogous operation performed by the pilot of an airplane. /33

The airplane reacts relatively rapidly to control inputs, while the spacecraft has considerable inertia. This leads to the necessity for training the cosmonaut on specialized trainers to develop these particular skills.

G. Titov was the first to perform manual orientation of a spacecraft in flight. In his report he had the following to say: "After an hour of flight, and in the dark of the night, I engaged the ship's manual control as scheduled in the flight plan. I must admit that this was not done without some trepidation, after all, no one had ever controlled a spacecraft in flight before. Would it follow the motions of my hands, I thought, and put my hand on the control stick. Vostok-2 obeyed my commands. It was easy to control the spacecraft. It could be oriented in any given attitude."

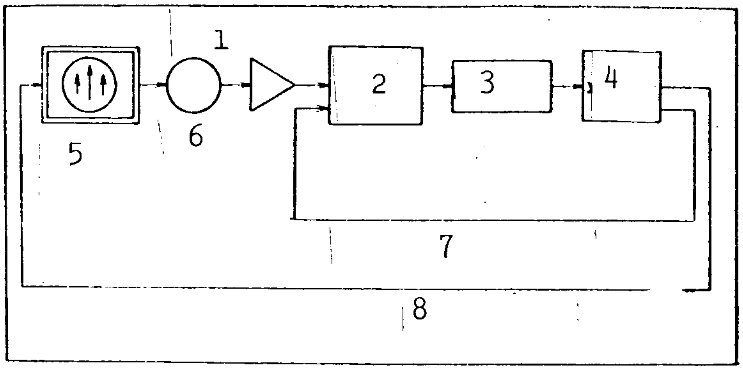


Figure 4. Block diagram of Vostok spacecraft manual orientation system

1 — control organ; 2 — angular velocity sensor; 3 — orientation engine; 4 — vehicle; 5 — Vzor orientator; 6 — cosmonaut; 7 — angular velocity feedback; 8 — angular position feedback

All the inputs made by man to the spacecraft and its systems can be divided into two groups: regulating and controlling actions. The objective of the former is to maintain certain parameters, temperature or pressure in the cabin, for example within definite limits. The controlling inputs, however, are intended to perform some particular program (for example, change of the spacecraft orbit in a definite space segment or perform a docking maneuver). /34

In performing rendezvous and docking operations the cosmonaut works in the tracking mode. In this mode the docking target displaces in space and the cosmonaut, perceiving these displacements directly, must control his ship so that he approaches the target precisely. By use of the control organs, he displaces the ship in a two-dimensional coordinate system. In this process, he must maintain the ship in a definitely oriented attitude at all times.

Concerning the rendezvous maneuver in the tracking mode, G. Beregova wrote the following: "During the first orbit Soyuz-2 was tracked by radio, and the process of automatic rendezvous of the ships to a distance of 200 meters was initiated. Then I took hold of the two control sticks, one located on each side of the seat. This rendezvous of the ships using manual control was a quite complex operation. It required good vision, spatial sensing, and a delicate so-called tactile sense, which made it possible for the pilot to adjust very precisely his forces with the complex motion of the flight vehicle.

"The maneuvering took place above the dark half of the earth's sphere — in the pitch darkness of the space night on a background of brightly shining stars. Here is where the experience in test flying to intercept aerial targets came in handy."

Radar operators, who try to maintain an airplane or rocket flying at high speed in the "field of view", also have to operate in a tracking situation, as do artillery gunners firing at moving targets, helmsmen holding a ship on course, and so on. But prior to flights in space, all the knowledge of tracking activity of operators had been obtained under earth-bound conditions. This is why studies were made on the Vostok and Voskhod spacecraft prior to conducting the very critical and complex operations involving maneuvering and docking spacecraft in orbit. These studies made it possible to identify the characteristics of man's tracking activity under space conditions. Such a problem was first posed to P. Popovich. He had the following to say about the results of the experiment: "I oriented the ship without any particular difficulty, and tried to track objects on the earth's surface. This was not hard to do. By use of the control stick I could "stop" objects on the surface and observe them in the central part of the Vzor sight.

"My next task was to orient the ship on the dark side of the earth. At this time the earth was illuminated by moonlight. The ship was oriented quickly, using the visible cloud cover. The clouds in the central part of the Vzor sight were light gray, /35 while those in the outer ring were white. It is not difficult to orient oneself using the clouds, one can even tell when they "move". This is easily seen because of the fact that the clouds are not continuous and the dark earth can be seen through the the gaps.

"I was able to maintain stars in the center of the Vzor sight quite well, which is very important for future astronomical observations. After locating a constellation, I selected quite a bright star, located to the right and high in the inner ring of the Vzor sight. As I watched, the star moved a little, and shifted nearly along the upper edge of the sight but a little below the edge. As soon as it approached the center, since I had already activated the orientation control, I deflected the control stick and drove the star to the center. My general conclusion was that it is possible not only to orient oneself by the stars in space, but also make atronomical observations of the stars."

From this observation we see that the cosmonaut, perceiving directly the "drift" of the star from the field of view, uses his inputs to the control organs to try to "retain" the star in the center of the Vzor sight. However, in his actions he lags somewhat behind the continuously moving object (in the case cited, the star remained fixed in place and the ship moved, but this does not alter the essence of the operator's actions in the tracking process), and tries to eliminate this lag in order to achieve fast and precise alignment of the sight (center of the Vzor instrument) and the target (the star).

It is particularly difficult to perform the tracking process, "sticking" to the target, when the operator cannot predict the changes in the signal movements. The operator tries to sort of guess the future movement of the target in direction and rate and even determine its motion by the sight. The skill in perceptive extrapolation, i.e., the ability to predict, is developed in the training process but is often realized subconsciously.

The psychologist William James wrote: "We can assume that a good two thirds of emotional life consists just of these preliminary thought schemes which are not clothed in words. How can we explain the fact that a man reading a book aloud for the first time is capable of giving his reading the correct expressive intonation if we do not suppose that upon reading the first phrase he already gets a rough idea of at least the form of the second phrase, which merges with his understanding of the meaning of the given phrase and alters in the mind of the reader his expression, forcing him to put the proper intonation in his voice? Expression of this sort nearly always depends entirely on the grammatical construction. If we read 'no more' we expect 'than' to be next, if we read 'although' we know that there will follow later 'however', 'nevertheless', 'still'" (cited from Ivanov, 1969, p. 247).

Using the methods of mathematical analysis developed in automatic control theory, and studying the nature of the changes taking place in the input signal as a result of its passage through the system under study, psychologists have been able to describe mathematically the dynamic properties of man operating in the tracking mode. It is well known that these functions /36 are the ratio of the images in the form of the Laplace transform of the signal at the system output to the signal at the system input. Therefore, experiments in which one of the authors (Leonov) participated were conducted aboard the Voskhod-2 spacecraft to study the influence of space flight factors on the ability of man to control objects in the tracking mode.

The data obtained were analyzed by E. A. Ivanov, V. A. Popov, and L. S. Khachaturyanets.

A signal in graphical form traveled over the screen of a special apparatus. The cosmonauts were assigned the task of following this signal with a sight-stylus which was rigidly connected with the control stick.

This technique was used to study cosmonaut reaction in the case of direct and delayed feedback, i.e., an inertial control system was simulated. In both cases, the cosmonaut's task was to minimize the difference between the input and output signals. The contrast of the given curve was about 0.85. The shape of the curves, the sequence in which they were shown, and the exposure duration were the same in all stages of the experiment. The tape feed past the screen was stable at 5 mm/sec. This made it possible to evaluate to some degree the latent periods of the cosmonaut's reactions under various conditions of preparation for and conduct of space flight. In all stages of the study, other than the in-flight investigations, the reaction measurements were made three or four times under normal conditions and with the simulation of certain space flight conditions which can be reproduced on the ground. The in-flight investigation was carried out twice. Each reaction measurement included 50 sinusoidal signals and 22 rectangular pulses, arranged in alternating order.

The data collected by the cosmonauts permitted statistical analysis using an electronic computer. Averaged results are shown in Figure 5, 6, and 7.

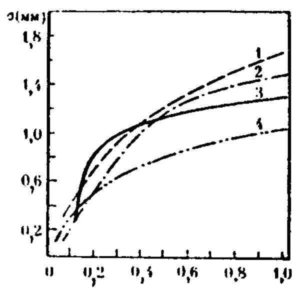


Figure 5. Mean square tracking error for A. A. Leonov in various flight stages

1 — space flight; 2 — prelaunch period; 3 — spacecraft trainer; 4 — ground trainer

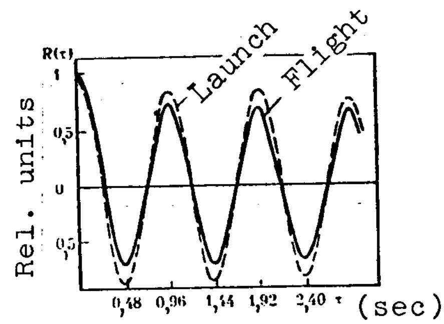


Figure 6. Autocorrelation function of tracking parameter for P. I. Belyayev

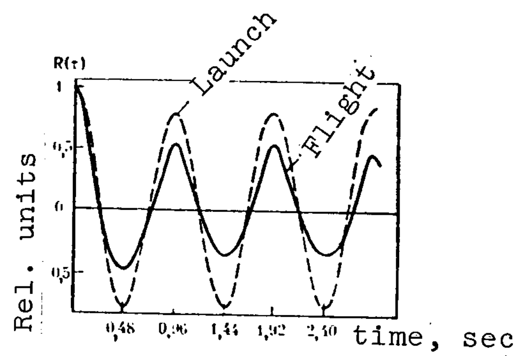


Figure 7. Autocorrelation function of tracking parameter for A. A. Leonov

The study of the dynamic characteristics of the cosmonauts in this experiment made it possible to determine: the amplitude-frequency characteristic [A (ω)], phase-frequency characteristic [ϕ (ω)], autocorrelation function (R); cross-correlation coefficient (r), transfer function, and certain other characteristics.

The input signals were in the form of a unit time function /38

$$U_{lin}(t) = A \cdot 1(t), \quad \text{for } A = \text{const}.$$

in the form of a linear time function

$$U_{lin}(t) = A \cdot (t), \quad \text{for } A = \text{const.}$$

in the form of a sinusoidal time function

$$U_{lin}(t) = A \sin \cdot \omega t \quad \text{for } A = \text{const.}$$

of noncritical frequencies in the range from 0 to 1 Hz.

In the first stage of the data analysis the mean square errors of the operator were determined for the various sinusoidal signals (see Figure 6). These data showed that the quality of human operator activity in the control of objects in the tracking mode changes under the different experimental conditions. The conditions of the external medium (influence of the space flight factors — mainly weightlessness, since the experiment was conducted during the seventh-eighth orbit) have more effect on control of signals with frequency above 0.5 Hz. The scatter of the errors in the prelaunch period is also high.

The data obtained using the two cosmonauts were identical in nature. This gave some basis for the authors cited above to consider that Leonov's walk in space had no significant influence on the quality of his subsequent control activity.

The dynamic characteristics of the cosmonaut-operators are most graphically illustrated with the aid of the autocorrelation function. Figures 6 and 7 show the corresponding curves obtained for both cosmonauts two hours prior to launch and during flight. Analysis of these curves (damped cosinusoids) shows, first, that the relative quality of the in-flight tracking is somewhat better for Leonov than for Belyayev, and, second, that there is deterioration of this form of activity for both cosmonauts in flight in comparison with the prelaunch period.

Studying the nature of the cosmonaut's reaction to the step-function input signal, the authors note a definite range of variations in the motor reaction latent period. Thus, the motor reaction latent period oscillated in the range from 175 to 185 sigma for Belyayev during training sessions in the spacecraft trainer, and during the prelaunch period. In flight this quantity amounted to 300 - 320 sigma. These marked variations in the magnitude of the motor reactions were not noted for Leonov. The /39 results obtained in the spacecraft trainer, during prelaunch and in flight, were similar and varied in the limits of 180 - 185 sigma.

Studies of the dynamic characteristics of the cosmonaut in the tracking mode were also made for the case with lagging (delayed) feedback for an input signal frequency of 0.06 Hz. According to Zinchenko and other authors, this technique makes it possible to study perceptive extrapolation, which we mentioned above. For these tests, the screen through which the cosmonaut tracked the input signal and the stylus-sight is partially covered by a shutter, so that the operator must essentially predict the behavior of the input signal, and on the basis of this act through the control organs on the stylus-sight.

The cross-correlation coefficients for the conditions with lagging feedback (signal 0.06 Hz) are expressed by the following quantities:

	Stage	Correlation coefficient
P. Belyayev	Spacecraft trainer	0.70
	Prelaunch	0.74
	In flight	0.83

	Stage	Correlation coefficient
A. Leonov	Spacecraft trainer	0.58
	Prelaunch	0.87
	In flight	0.88

We see that the data obtained in flight are better than the values obtained on the ground. Worthy of note is the opposite tendency of the changes in work characteristics of an operator in flight in the absence of feedback without delay, and feedback with delay. At the present time we are not able to explain the reason for this fact. In all probability only further studies under outer space conditions will make it possible to explore and explain these phenomena. However, the experiment conducted makes it possible to conclude that man's dynamic characteristics under the influence of one-day space flights do not undergo any very serious changes. This experiment also showed that human activity with an input signal having a frequency higher than 0.5 Hz was most influenced by the space flight factors.

The cosmonaut's activity as an operator is not limited simply to control of the ship in space and observation of the operation of the on-board systems. Radio communications are also an important cosmonaut activity. Radio transmission sometimes reaches /40 high rates while the cosmonaut is at the same time performing functions involved with controlling the ship and its systems. An example of this radio communication rate is Leonov's walk in space. During this task there were 460 radio transmissions between Belyayev and Leonov, and also with the ground control stations.

Following is part of the radio conversation during Leonov's space walk:

Leonov: The airlock hatch is opening. I see light. The airlock hatch is moving. The airlock hatch is fully open.

Belyayev: Roger, roger. Zarya-4, this is Almaz. I read you. Almaz-2 just opened the airlock hatch, the hatch is open. Everything is going fine. All's going well. This is Almaz, over. Lesha, give me a report. How are things going, Lesha?

Leonov: Everything's fine. I'm already at the edge.

Belyayev: Almaz-2 is going out. Is the movie camera on?

Leonov: Roger. This is Almaz-2. I'm taking off the cover. Throwing it away. The Caucasus! The Caucasus! I see the Caucasus down below. I'm moving away.

Belyayev: This is Almaz. The shifting of the mass is affecting the ship.

Leonov: Watch out, I'm approaching the airlock.

Belyayev: OK, OK, I see you fine.

Leonov: I'm starting to move away again. It seems to me that my position affects the ship.

Belyayev: This is Almaz. When Leonov moves away from the ship it affects the ship as a whole... You're well away now, how are things going, Lesha?

Leonov: Fine! Fine!

. . . .

Belyayev: Two minutes left!

Leonov: OK, OK. Right away. I can't get the movie camera loose.

Belyayev: Get ready to come back in.

Leonov: Roger, roger. I got the movie camera loose, its loose!

Belyayev: Almaz-2 feels fine. He is entering the airlock. He got the movie camera. Lesha, take a rest. Don't talk. Are you in the airlock?

Leonov: I'm in, I'm in!

Belyayev: When you're ready tell me to close the hatch.

Leonov: You can close it now.

Belyayev: I'm closing the airlock hatch. I'm closing the hatch.

Leonov: It's closing. The hatch cover is closing.

Belyayev: Vesna, Zarya. This is Almaz. Almaz-2 is in the airlock chamber. The airlock hatch is closed. Everything is A-OK. This is Almaz, over.

As a spacecraft travels further from our planet, radio communications cannot be carried out in the "telephone conversation" mode as in the above example. We have already mentioned that radio signal transmission time will be about 2.5 seconds when the vehicle is in a selenocentric orbit or on the surface of the moon. Therefore, when making radio transmissions at these /41 distances the cosmonauts will receive certain information in the form of a message and will transmit the answer in the same form. This is reminiscent of the exchange of telegrams between two individuals located in different cities on the earth's surface.

Experience in orbital flights has shown that when conducting radio communications with control stations and spacecraft, various errors may arise in both information transmission and reception. As an illustration we shall reproduce several examples from the book "Psychology and Space", written by Gagarin and one of the present authors.

During the first day-long flight Titov, carried on intensive radio communications with the ground control stations. "The only case when they did not understand me on the ground," he said, "was not the fault of the radio equipment. I heard music on one of the short wavelengths. The station in the Far East was playing a record of the 'Amur Waves' waltz. I love that waltz and when the station operator asked: Well, how did you like that?', I answered: 'Thanks, I liked it.' The station operator immediately put the tape on again. Then again, and again, and again. I transmitted: 'Thanks friends, but change the record.' 'I read you,' the answer came back. And after a minute of silence I again heard . . . 'Amur Waves'. That's how well they understood."

A no less comical case occurred with Vostok-5. During his five-day flight Bykovskiy reported on the radio that "for the first time there was a space rocker." At the control station this message we received as "space knock". Naturally this message caused some concern, since they figured the cause of the "space knock" was an encounter with a meteoritic body. The concern over the cosmonaut continued for nearly an hour, since the ship went out of radio communication coverage on the UHF channel during this time. As soon as he entered the next radio communication zone in the next orbit, questions were immediately asked about the nature of the knock, where and when the cosmonaut heard the knock, what was the cabin pressure, and so on. Only after a new radio exchange was the concern over the cosmonaut alleviated and the information understood properly.

While in these flights erroneous reception and transmission of information was rectified after a comparatively short break in communications, in the case of long interruptions incorrectly received information, and therefore incorrect conclusions and inferences made on the basis of this information, could lead to undesirable consequences. But even in the case of correctly re- /42
ceived information of a nonstandard nature, the operator may come to incorrect conclusions under certain circumstances. The operator bases his activity on the information stored in his memory and the information transmitted from the control center. Erroneous conclusions may also arise in the case of transmission of insufficiently complete information concerning a particular event. It seems to us that the observation of cosmonaut K, made together with O. N. Kuznetsov by one of the present authors, can serve as a model of such a situation.

Cosmonaut K was undergoing a test for neuropsychic stability in an isolation chamber. On the tenth day of the test, which fell on a Sunday, he had a conversation with the designer S. P. Korolev.

The senior medical officer, after switching on the interphone system, said: "Comrade K, designer Korolev would like to speak with you." The cosmonaut replied that he was ready to talk with Korolev but that he would prefer not to be doing it from the isolation chamber. Korolev congratulated K on his successful conduct of the test to date and wished him successful completion of the test. The cosmonaut thanked him for the warm greetings and this was the end of the conversation.

The information obtained by the cosmonaut in the isolation chamber did not in itself contain any false data, but because of its incompleteness it was interpreted erroneously. In his final report after the experiment the cosmonaut said: "The conversation made me think as follows. First it was Sunday; second, it was in the evening — and suddenly designer Korolev appears in the isolation chamber control room. When the conversation began I decided that this was the end of the test, they are going to let me out. When they said Sergey Pavlovich another thought came to me: 'This means they are not going to let me out. They're just putting on a show. But why is he here?' Isolation had led me to have strange thoughts. I decided that I had probably been given some flight assignment. That's why Korolev is here even on a Sunday evening and is going to discuss this assignment."

The incorrectly interpreted information caused emotional stimulation of the cosmonaut which continued until the end of the experiment and affected the results of his performance of the experimental-psychological tests and soundness of his sleep.

The lack of information on what was going on in the City of the Stars and chance coincidence (conversation with Korolev in the evening hours of a day off) led to a very subjective probable conclusion, closely associated with the professional interests of the cosmonaut. The real reason for Korolev's visit to the city, being subjectively unlikely, and not associated with the circle of interests of the cosmonaut, was not taken into consideration by the cosmonaut at all.

It seems to us that this is a very good model of the situation in which correct but insufficiently complete information, obtained under conditions which do not permit the cosmonaut to learn any more, can be associated with random circumstances and lead to false conclusions. /43

In long-duration flights the professional cosmonaut will act not only as an operator, but also as a technician. In case of failures of the automatic equipment or any other breakdowns in the hardware, he will be faced not only with the task of finding the cause for the equipment malfunction, but also putting the hardware back into working order. To do this the cosmonaut must know the spacecraft systems and equipment perfectly.

In order to study the construction of the spacecraft and its systems, the cosmonaut participates in the mockup activity, layout of the ship, development and checkout of its systems in the testing laboratories and on the launch pad, participates in technical meetings to resolve problems which arise, and helps in writing and rewriting the flight plan and flight documentation. It is obvious that these questions can be resolved only by a cosmonaut who has a good engineering and technical background. This training occupies an important place in the over-all system of cosmonaut preparation.

In the rapid development of space technology, the single-place Vostok and Mercury flight vehicles have been replaced by the multiplace Voskhod, Soyuz, Gemini, and Apollo ships. In this connection, space psychology has been faced with the question of multiplace spacecraft crew teamwork.

IMPORTANCE OF CREW TEAMWORK IN CONTROLLING A MULTIPLACE SPACECRAFT

> Engineering psychology must not forget the fact that it deals with man — a social creature, the subject of work and social relations, and the subject of life in all its fullness.
>
> A. N. Leont'yev

The flight of the multiplace Voskhod spacecraft with the crew consisting of pilot-cosmonaut V. Komarov as commander, scientist K. Feoktistov, and doctor B. Yegorov was a qualitatively new step in the exploration of outer space. The Soviet multiplace Voskhod spacecraft is the harbinger of a class of spacecraft which will permit man to visit Mars and the other planets.

In carrying out space flights on the Voskhod and Mercury spacecraft the cosmonaut performed navigational, piloting, and other functions in the man-spacecraft system. The spacecraft controlled by a crew consisting of several individuals is a more /44 complex system. In this system there is a division of functions among the crew members: commander, flight engineer, radio operator, and so on. Without going into great detail, we shall simply note here that during long space flights each crew member will perform several functions. But we emphasize that each individual in the multiplace spacecraft, while controlling "his" hardware, is associated with the other crew members and also with the hardware and system as a whole, which can be characterized as a "man-man-machine" system.

Thus, on the one hand, relatively narrow specialization and separation of the piloting, navigating, communicating, and other functions leads to more highly skilled performance of the tasks of controlling the multiplace spacecraft in comparison with the single-place ship, where all these functions are performed by a single man. On the other hand, this division of functions among the crew of the multiplace ships requires precise coordination of the actions, profound mutual understanding between the members of the crew, skill in performing operations to supplement the work of another crewman in order to perform a common task successfully. Only in this way can the very complex problems which face the spacecraft crew in carrying out the flight mission be solved at a high level.

Crew teamwork shows up most clearly in performing tasks under time deficit conditions. These cases disclose the inadequacy of a general correct understanding of the task by each member of the crew and the crewman's high awareness and quite high professional skills for successful performance of the task facing the crew as a whole. Even experience in modern aviation has shown the need for a high degree of teamwork among the crew members, which in small-group psychology is called "psychological compatibility". This teamwork may not always be sufficiently good, and in such cases, in spite of the fact that the pilot, navigator, radioman, and operator perform their individual functions quite well, integrated performance of the complex airplane control problems is not achieved. In such cases, neither analyses, nor administrative or social measures are of any help. Each of the crew members feels the common failure deeply, but the results do not improve. As a rule, "psychological incompatibility" between the crew members shows up in the performance of critical ship maneuvers (landing under instrument conditions, aerial refueling, "blind" bombing, and so on). The conflicts develop most sharply under these conditions and sometimes the members of such psychophysiologically incompatible crews develop neuroses. We present the following observation as an example.

A transport airplane crew consisting of four members (pilot, copilot, navigator, and radioman) experienced problems while performing the most critical and difficult operations (night parachute drops and instrument landing approaches) which could lead to an accident (imprecise approach of the airplane to the landing trajectory, errors in dropping parachutists, and others) because of uncoordinated actions of the navigator and the pilot. As a result of this, the professional activity of the crew took place with excessive emotional stress among all the crew members, and quite frequent and stormy conflicts developed between the pilot and the navigator, which led to the development of personal animosity. As a result of long-term professional psychotraumatism, the navigator developed neurasthenia, which made it necessary to relieve him of flight duty for a period of time, and the pilot was found to have a duodenal ulcer. After treatment, the navigator and pilot were assigned to other crews, and continued their flight activity with no problems. There were no relapses among the crew members during six years of subsequent observation.

Instructor pilot G. I. Kalashnik writes: "Experience suggests that where the professional preparation and discipline of each member of the crew is maintained in the group by cooperation and mutual assistance, success is assured.

"The pilot, radioman, flight engineer, and navigator must know their jobs perfectly. But they must also know well what is involved in the range of duties of their fellow crew members, and must, if necessary, act as backup for one another.

"I can remember dozens of cases when the absence in the crew of backup capabilities, mutual monitoring, and the feeling of crew solidarity led to serious flight accidents.

"Under difficult conditions (flight with 'weather ceilings', failure of equipment, and so on), the crew's 'strength and integrity' are put to the test. It's a bad situation if under these conditions each crewman begins to twiddle his thumbs and rely only on the commmander.

"An emergency situation should not catch the crew unawares. Here everyone should be on the alert and the team should act as a single unit. Obviously this confidence in one another comes with time. Only long periods of working together make it possible to know one another's capabilities."

At first glance it may seem that the basis for lack of teamwork in the crew might be the absence of friendly relationships, lack of regard for one another, or even dislike of one another. A more profound analysis shows that the basic reason for lack of unity among the crew members lies in the absence of the proper contact and mutual understanding of the flight activity, accompanied by failures in flight operations. /46

The experienced commander and human engineer skillfully identifies the individual psychological characteristics of a poor flight crew, and on the basis of empirical experience, he can usually resolve correctly the problem of reassigning crews. Most often a pilot who is not working well with his crew is assigned an experienced navigator who has flown with many pilots, while a navigator who is not working well with the rest of the crew is assigned to the crew of a highly experienced pilot. Jumping ahead somewhat, we can say that from the viewpoint of small-group psychology the pilot who has flown with various navigators and the navigator who has flown with many pilots have a broad range of capability for understanding, coping with, and adapting to different individual characteristics. This then ensures the development of the required teamwork in their joint activity and the achievement of excellent results in flight operations.

There were reports that during World War II one of the American aerial bombing units was suffering serious losses. The psychologists suggested a solution: crews were shifted around in accordance with the results of psychological tests and the losses were reduced sharply (citation from Ryzhov, 1967). From this we might conclude that crew selection for a spacecraft is quite simple: pick the required specialists, study the individual psychological characteristics of each, and start training the group selected in this fashion. However, we know that a team composed of individually strong athletes — "stars" — sometimes loses to a team comprised of weaker players who play well together.

Experimental studies have also shown that even if we know well the individual characteristics of each of the members of a group, we can by no means always predict from an experiment simulating the group activity how successful the activity of this group as a whole will be, and what interrelationships will develop between the individual members of the group. Knowledge of the individual personality characteristics does not make it possible to judge how the actions of a particular individual will fit in with the actions of the group. A group is not the arithmetic sum of the individuals, but rather a unified organism, in which special relationships begin to show up.

While in aviation, teamwork is developed in the process of repeated flights as members of a crew, and in the case of psychophysiological incompatibility there is the possibility of reassigning crew members, this possibility does not exist in the case of space flight. Therefore the human engineers and psychologists are faced with the problem of selecting and training a well-coordinated crew prior to a flight directly into outer space.

This is why it is urgent to study the relationships which come into play in small groups and develop scientific methods for the selection and training of highly coordinated spacecraft crews. /47

The relationships which determine the "psychological compatibility" of a group of people are of interest not only to space psychologists, but also to production organizers, sports team coaches, commanders of military units, i.e., everyone associated with the organization of individuals into a group for the performance of a particular task.

Concrete studies in the field of "collective reflexology" were initiated by the Russian psychoneurologist V. M. Bekhterev. Studies on rational staffing of production groups to increase labor productivity were conducted in the Soviet Union in the 1930's at the Institute of Work Safety (O. P. Kaufman, R. I. Pochtareva, and P. G. Markir). Detailed recordings of the work rate variation of each member of this combined group showed an interesting relationship which made possible a somewhat more profound analysis of the reasons for microvariations during long-term operation. In spite of the fact that the group was not selected to have individuals with the same working rates, and therefore we would expect a reduction of the work speed because of slow workers holding the faster workers back, it was found that the work rate in the entire group was not only accelerated (in comparison with the individual rates), but the work rate became relatively more uniform. Even these initial observations showed that under collective working conditions a powerful new factor acts as an objective stimulus — this is the operating cycle of another individual working alongside a given worker.

Experience in the preparation of sports teams gives dramatic evidence of the importance of proper and rational selection of individual members and their teamwork. Today's high level of development in sports emphasizes the psychological factors, particularly the problem of team "togetherness", i.e., that combination of individual player tactics which ensures an optimal strategy of the entire group. Doctor and psychologist M. Novikov, speaking of "teamwork", indicates that it is assured by the existence of highly developed interconnections in the team and understanding of the partner's pattern of play. For example, the famous Brazilian soccer player Pele, answering questions of correspondents, characterized what he felt to be the "ideal" partner, the young forward of the Brazilian all-star team, Kutinho, as a player who is capable of guessing his (Pele's) moves.

Here we should note that although this "understanding" of your partner's play has a superficially intuitive nature, in actuality this can be explained by the development of a feeling for probable behavior.

Extensive sports experience also indicates that "togetherness", just like crew coordination, is achieved only by combined training in the course of a long time period. /48

In a newly formed and isolated group, "leaders" and "followers" nearly always show up. A leader is one who imposes his will on the others, determining the tactics (line of behavior) of the entire group in the solution of any particular problem.

It is particularly easy to investigate such group structure in team sports. There the "leader" is either one who by active actions "takes over the play", as we say, or skillfully guides the actions of his partner.

Speaking of "leaders" and "followers", we should mention the error of the idea that the "leader" is the best member of the group and that the "followers" are second-rate members of the group. In reality the leaders and followers are equally important in the group.

A particularly large contribution to the development of group psychology has been made by the team of Soviet scientists headed by Professor F. D. Gorbov. This team of scientists has suggested several scientifically based experimental psychological methods which have made it possible to determine how successful the activity of the group as a whole will be, and what requirements are made on the individual psychological characteristics of the personaltiy of each member of a specific group. Gorbov and M. A. Novikov with the participation of Professor Ye.S. Venttsel' and I.Ye. Tsibulevskiy developed the so-called homeostatic technique for studying the integral activity of a group as a whole, and clarifying the position of each group member. It is interesting that the basis for the development of this technique was Gorbov's observation of the operation of a shower room of one of the Moscow medical clinics. In this shower room there were four cubicles, but the pipe diameter did not provide all the bathers with an adequate amount of hot water. When four people entered the cubicles at the same time it was possible to observe various actions of the bathers, taken with the objective of creating a

regime close to optimal. An attempt by one individual to achieve the best conditions led to cold water beginning to flow to the other cubicles, and this caused a reaction from the other bathers. They began to turn their valves and as a result either cold water or excessively hot water poured onto the first bather. Only by avoiding egocentric tendencies was it possible to set a regime satisfactory for all, which required "struggles" between various action plans in a game situation. At times some one in the group quite rapidly stood out and took upon himself the "guidance", i.e., he became the "leader". When two or three individuals contested for the leadership at the same time, the group became a coordinated unit much more slowly. Such groups could not manage the shower installation for a long time, or sometimes not at all, interfering with one another all the time. The situation was
particularly bad when an individual who was not accustomed to /49
consider others was a member of the group. As soon as this individual left the shower the remaining individuals quickly regulated the water supply regime.

An experimental reproduction of a situation close to that of the "shower" was reproduced on a "homeostat" device. The homeostat consisted of three or more consoles (one for each subject). The task for each of the members of the test group was to set the pointer of an indicator to a zero mark. All the operators' consoles were interconnected. During the test each of the subjects, while obtaining information from his own indicator, could act on this indicator only indirectly, through action on the indicators of his partners in the group. The experimenter could vary the difficulty of the problems being solved from his control console. The task was considered complete when all the operators had set their pointers to the zero mark. Recording of the movement of all the knobs and all the pointers on an oscillograph made it possible to investigate not only the nature of the action of the entire group as a whole but also the tactics of each of the group members.

These studies established that group effectiveness cannot be predicted on the basis of a priori individual criteria. Moreover, when intensifying the mutual couplings between the members of the group, it was found to be necessary to alter the strategy of the group as a whole, and replace the "parity" principle of operation by the "authoritative" principle. Conflict-type situations between group members were noted during the solution of the most complex problems in these experiments. We shall present some of Novikov's observations.

Subject A wants to be the leader of the group. However, this level of individual pretension is not supported by his selection of leadership tactics; he always adheres to primitive, inflexible tactics. In his behavior he is intolerant of the others. In spite of the instruction not to converse with his partners, he instructs, criticizes, and needles his partner "Ivan", who works more slowly but quite adequately. He becomes nervous, shakes his head in annoyance, and sometimes rotates his console control knob sharply and angrily to the right or left, thus causing disturbances of the indicators which are illogical and confuse his partners. During the operation he makes unmotivated actions which are dictated by his annoyance.

In those cases in which the needle which has been slowly traveling in the right direction unexpectedly and rapidly moves away from the zero mark, subject P becomes highly indignant, quits working, saying: "I don't know what to do." "I'm not going to fool with it any more, it won't ever stop," and so on.

There are three members in a group. They are having difficulty solving the problems on the homeostat. Subject D is always belittling subject T: "You should be hauling lumber rather than working with a potentiometer." Toward the end of the problem he began to criticize subject R. R was also very deprecating of subject T. As a result of lack of coordination in their work, all the subjects developed unfriendly relationships with one another. /50

Novikov used the following technique for a special study of conflict situations during the work with the homeostat. In the first stage of the experiment, the group was trained and operating skills were developed. In the experiments there were 27 groups of subjects with 2 - 3 or more members in each group. In the second stage of the experiment on operator activity, when the operation was approaching the goal, i.e., the equilibrium state, the experimenter introduced disconcerting "noise" from his control console. During the experiment, recordings were made not only of the operator activity parameters, but also of the vegetative reactions of the subjects (pulse, respiration rate, galvanic skin reflex, and so on).

The results obtained showed convincingly that the introduction of disconcerting "noise" as the system approached the stable state caused a conflict situation, accompanied by neurotic reactions which are expressed in disruption of the previously developed dynamic stereotype in the operator activity, even to the extent of loss of skill and inability to solve the problem, and also change of the emotional-vegetative background of the behavioral reactions.

All the subjects for which neurotic reactions were recorded can be divided into two groups.

Characteristic for the first group, constituting the majority, is dominance of behavioral reactions expressed in emotional and speech uninhibitedness of the subjects, inadequate attention fixation. The following observation can be used as an example of such a reaction. Engineer V, not understanding the essence of the disconcerting noise, transferred his irritation to the instrument and his partners in the experiment. He shouted irritatedly that the instrument was constructed improperly, stupidly, that his partners were stupid and untalented, and so on.

Bystritskaya and Novikov termed this type of behavioral reaction to conflict a "local conflict", differentiating it from a "diffuse conflict", in which there is no selection of an object for relief of the conflict, and the subject refuses to continue the experiment further.

Both individual experimental psychological techniques and the theory developed in small-group psychology were naturally used in selecting the first multiplace spacecraft crews.

It is well known that the individuals who were trained for flight on the Voskhod spacecraft were strong-willed, each had high professional qualifications as specialists in particular fields of knowledge, and understood fully the responsibility of the task assigned him. The human engineers, medical psycholo- /51 gists, and training specialists studied carefully the psychophysiological compatibility of the crew. Obviously, the matter was not limited to experimental psychological investigations. Their group activity was studied on the spacecraft trainer, during sports training, and during work and rest periods.

During the initial stage of their preparation, there was both combined training of the main and backup crews as a whole, and individual work with scientific personnel and the doctor. The latter helped in developing such skills as the handling of radio communications, use of the life support equipment, and so on.

Since the time for the preparation of the scientist and doctor members of the crew, who had not had previous flight training, was limited, there was no possibility of providing complete interchangeability of all crew members.

Then the cosmonauts went through training programs on the Voskhod spacecraft trainer with the crew operating as a unit to learn the in-flight operations. The combined training made it possible for each member of the crew to get a feel for and appreciate various aspects of the activity of the other crew members, and to find the best technique for his own activity. In order to study group teamwork, special attention was devoted to interaction precision when performing operations requiring participation of all three crew members.

The integrated training in the spacecraft trainer, conducted in real time, showed that the crew worked smoothly together, understood one another, showed mutual understanding and interaction, which made it possible to predict successful performance of the flight mission. However, the high evaluation of the crew as a whole did not exclude differences which depended on the individual psychological characteristics of each individual crew member.

During the training sessions, the Voskhod spacecraft commander Komarov was relaxed and composed. During the preparation for each exercise, he tried to ensure that he had a clear understanding of the task. After completing the exercise he made systematic, complete, objective, and self-critical reports.

During the joint training sessions Komarov's exceptional qualities as a capable leader showed up clearly. He unified and organized the crew tactfully, delicately, but insistently for integrated, creative performance of the critical mission.

Characteristic of the scientist Feoktistov was innovative, goal-oriented thinking in the preparation for each training session. During the training sessions, he demonstrated a high degree of keenness of observation, perseverance in the detailed study of all the scientific observations and studies being carried out by the crew. Typical of Feoktistov was the creative conduct of each training session, and the original solution of certain appar- /52
ently previously settled and stereotyped questions.

Characteristic of the doctor Yegorov was a very profound analysis of his own actions during the training sessions, broad understanding of the importance of the programmed medical investigations, emotional restraint, persistence in overcoming difficulties in developing and retention of his professional actions, and also judicious initiative.

Characteristic of the crew as a whole was a unified understanding of the flight goal, ability to direct all efforts toward the performance at a difficult moment of any spacecraft control task associated with control of the spacecraft, its systems, the scientific and medical studies, and to subordinate their individual tasks to the solution of the basic objective.

It is interesting to note that the characteristics of the group structure of the Voskhod crew showed up quite clearly in the organization of the sports games and recreation during the preflight rest period under sanatorium conditions, and in other everyday and training situations.

We know that the flight of the Voskhod spacecraft was successful and the scientific experiment program was performed in its entirety. In this connection, Komarov's report on in-flight operation of the first multiple space crew is of considerable interest. "The scientific investigation program," wrote Komarov, "was planned for one day and the crew performed the program completely. The tasks which we had to perform in this flight required the participation of all the crew members. One individual could not perform them all, no matter how well he was prepared. This required, in turn, not only the same understanding of the problems by all the crew members, but also excellent teamwork, immediate understanding of one another, and even interchangeability.

"Although our crew in space was small, it operated as a harmonious Soviet collective, proud in the knowledge that we were performing our work in the name of peaceful goals, for the welfare of all mankind.

"All the crew members assisted one another creatively in performing the complex and interesting work outlined in our flight plan.

"Naturally, all this did not take place without some effort. Before entering the Voskhod cabin, its crew worked long and hard, studied and trained."

The high degree of teamwork and mutual understanding between the crew members is eloquently expressed in the words of Komarov, who with his typical modesty characterized his tasks as commander as follows: "I should explain that a spacecraft commander is not like a military unit commander. I did not do any commanding, rather I had no need to do so. We all knew our duties and each performed them skillfully."

A particularly high degree of coordination and teamwork was required of the crew of the Voskhod-2 spacecraft. It is obvious that such a complex problem as exit of man into space from the spacecraft cabin through an airlock can be successfully accomplished only with the aid of a high degree of teamwork, mutual understanding, confidence, and faith of the cosmonauts in one another. /53

In dividing the duties between the crew members, consideration was given not so much to their professional preparation, since both cosmonauts were highly qualified professionally, but rather to their individual psychological qualities. The features most characteristic of Belyayev were strong will and tenacity, calm reaction in dangerous situations, logical thinking with profound self-analysis, and great perseverance in overcoming difficulties in achieving the posed objective.

With regard to his temperament, Leonov is of the choleric type. Strong and impetuous, he is capable of carrying out tireless activity and demonstrating courage. His synthetic way of thinking, combined with his artistic ability, make it possible for him to envisage and memorize in brief moments of time entire pictures, and then reproduce them quite faithfully.

These two cosmonauts, different in nature but supplementing one another and forming a highly compatible team, performed their flight very successfully and brought a large amount of valuable information back from space. The following minor incident in their work during the flight is indicative of the correctness of the selected team, and the division of duties between them. When Leonov entered the airlock and Belyayev reduced the pressure in the lock, Leonov began to ask permission from the commander to open the outer airlock hatch and go out into space before the scheduled time. But Belyayev opened the hatch precisely in accordance with the flight plan.

One aspect of the crew preparation for the Voskhod-2 spacecraft was that in addition to the development of skills in controlling the spacecraft and its several systems, which did not differ fundamentally from the preparation for the preceding flights, the cosmonauts had to train for working under conditions of hard vacuum and support-free space.

In performing the docking operations with the Soyuz-4 and Soyuz-5 spacecraft, it was necessary to work out the combined functions of the two spacecraft crews. The successfully conducted operation was preceded by numerous training sessions on various simulators. The docking process was worked out both separately by Shatalov and Volynov, and in the course of combined training sessions. Combined operations involved with transition of the cosmonauts from one spacecraft to the other were also worked out.

After termination of the group flights, all the cosmonauts repeatedly emphasized that the successful completion of a flight with such complex experiments as the spacewalk and docking of the two spacecraft was assisted by the teamwork achieved in the combined training sessions in the course of the entire flight preparation period. /54

However, the problem of psychophysiological compatibility is not limited to simply crew teamwork in controlling the spacecraft and their systems. During extended space flights, the crews must not only work together but also rest together, i.e., they must live together under complex conditions of extended group isolation. Here mutual sympathy, friendship, community of viewpoints, and so on, in general everything that creates a monolithic unified team, become important in the interrelationships between the members of the team. But this aspect of the problem goes beyond the scope of operator activity, and will not be considered here.

In concluding this section, we note although group psychology cannot at the present time give a complete answer to many practical questions, it does seem to us that, on the basis of group psychology data, we can now define the technique for multiplace spacecraft crew selection in preparation for extended space flight.

After experimental psychological studies are made to verify the possibility of combined work in controlling the spacecraft, the crew assigned for an extended space flight must not only carry out together various forms of training and testing during the period of preparation for the flight, but must also relax together.

While prior to the individual space flights all the cosmonauts went through neuropsychic stability testing in the isolation chamber, the members of the multiplace crew will, in all probability, be tested for psychophysiological compatibility.

All this will permit the psychologists, human engineers, training specialists, and doctors to study carefully the psychophysiological compatibility of the crew, and to train and "integrate" the crew. This will also permit identification of individuals who are not suited as crew members for the proposed flight.

PSYCHOLOGICAL APSECTS OF PREPARING COSMONAUTS AS OPERATORS

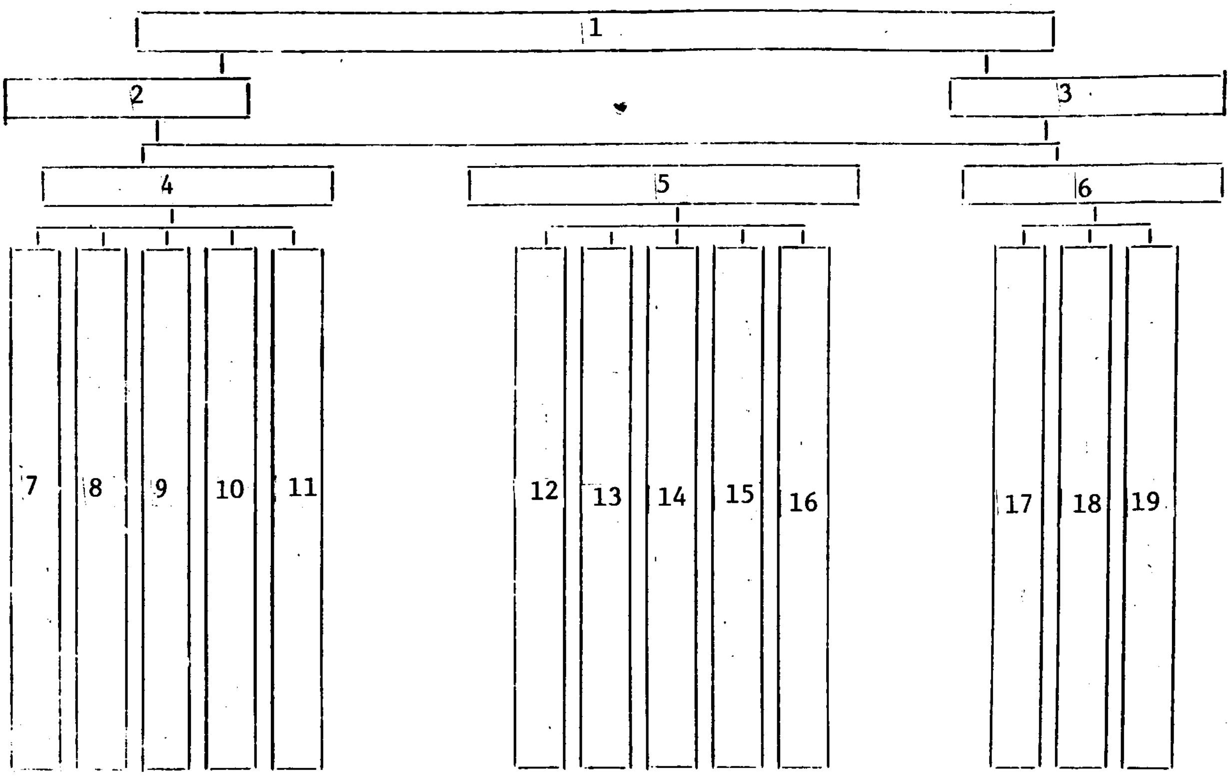
We know from experience in pilot training that after completing a theoretical course and training sessions on simulators in flight school, students have the flight skills for piloting training planes with dual controls. The first flights are always /55
made with an experienced instructor, who can, in the case of serious errors by the student, intervene in the control of the airplane at any time and thereby prevent unpleasant consequences.

Training spacecraft have not yet been built which are capable of "taking" the cosmonauts into outer space in the preparation process for a final honing of the professional skills in controlling the spacecraft under realistic conditions. Thus, while the primary mode of pilot preparation involves training flights in airplanes, and simulator training is of secondary importance, simulator training becomes of decisive importance in the professional preparation of the cosmonauts.

Therefore the requirements for ground trainers and simulators for the cosmonauts will be particularly severe. The simulators and trainers must simulate space flight conditions and factors, emergency situations, operation of the individual systems and the flight dynamics, and also ensure development of the required skills in controlling the spacecraft and its systems (See page 78).

The simulators used to develop the cosmonauts' professional skills are shown in the diagram.

DIAGRAM



1 — trainers for developing cosmonaut professional skills; 2 — dynamic trainers; 3 — static trainers; 4 — functional trainers; 5 — specialized trainers; 6 — combined trainers; 7 — spacecraft instrument and system trainers; 8 — spacecraft manual control simulators; 9 — life support system simulators; 10 — optical system trainers; 11 — radio equipment simulators; 12 — ecological system control trainers; 13 — space rendezvous, mooring, and docking trainers; 14 — landing and takeoff trainers for the moon, Mars, and other planets; 15 — trainers for solving specialized problems (spacewalk and so on); 16 — piloting and navigation trainers; 17 — space station crew trainers; 18 — multiplace spacecraft trainers; 19 — single place spacecraft trainers

We see from this diagram that all the trainers can be divided into dynamic and static. The basis of this division is the principle of trainer motion together with the cosmonauts' work station. For example, the specialized trainer for working out the landing of the spacecraft on the moon moves in space, and the cosmonaut experiences both angular and linear accelerations; the functional spacecraft control trainer, located in a centrifuge capsule, is designed for developing control skills under conditions with load factors acting.

In the static trainers, accelerations do not act on the individual and the cabin or work station is stationary. However, it seems to us that trainers which do not move, but in which dynamic changes of the medium surrounding the cosmonaut are created, should be considered dynamic trainers. For example, when developing skills in an altitude chamber related with the functions of the airlock and work outside the spacecraft, the cosmonaut is subject to high vacuum, which has a definite dynamic nature.

The functional trainers, which we see from the diagram are widely used in the cosmonaut preparation system, are designed to develop professional skills in the operation of individual instruments or one of the many spacecraft systems (for example, development of skills in conducting radio communications). Training of the cosmonauts on the functional trainers ensures highly efficient and rapid development of the individual professional skills, since under these conditions the cosmonaut's /57 attention is concentrated on developing only one particular skill.

The cosmonauts use specialized trainers to develop skills in performing particular tasks outlined in the program for the specific space flight. Such tasks may be space walks, docking with another ship or orbital station, landing on and taking off from the moon, and so on. Thus, the specialized trainers are used to develop only those skills which are required for performing specific tasks. Therefore, the specialized trainers simulate only the systems and information sources which the cosmonaut will utilize in performing these tasks.

But all the skills acquired by the cosmonauts during the training sessions on the functional and specialized trainers are integrated in the combined training sessions on the complex integrated trainers.

The first such integrated simulator on which the cosmonauts trained was the Vostok spacecraft simulator, which included the full-scale space vehicle, equipment for simulating the image of the moving earth and stellar sky, the instructor's console, and the electrophysiological equipment for recording the physiological functions. The space vehicle cabin included all the instruments and systems (instrument panel, pilot's console, control stick, conditioning system, radio equipment, and so on), which are arranged just as in the Vostok ship intended for the next space flight.

During the cosmonaut training sessions, an electronic computer is used to simulate during all the flight segments, beginning with the launch, orbital flight, and landing on the earth, the instrument indications (command transmission, indications of changes of the gas composition of the air in the cabin and the pressures in the orientation system tanks, the location of the spacecraft on the Globus instrument, and so on). Introduction into the electronic computer of the corresponding programs provides complete similarity of the simulated instrument indications with the instrument indications in actual space flight. The trainer computer makes it possible to simulate the flight dynamics processes both in real time and in an altered (accelerated) time scale, which makes it possible in the training sessions to "run through" the flight segments in which the cosmonaut is relatively inactive as an operator and "play back" in real time those flight segments in which the cosmonaut must work fast and under strain.

In order to develop skill in manual control of the angular motions of the spacecraft on the trainer, use is made of a loop simulating manual attitude control. This loop includes the attitude control system simulator, an angular dynamics computer, /58
and simulation of the visible image of the earth and sky.

The view of the earth and the stellar sky is reproduced with the aid of an electro-optical device. In this device, use is made of a unique planetarium which reproduces the natural displacement of the celestial bodies, and also the motion of the entire sky as a function of the spacecraft flight segment.

In developing manual attitude control skills, the dynamics of the angular motions in controlling the spacecraft are also simulated with the aid of an electronic computer. The image of the earth's surface and stellar sky in the Vzor optical sight moves in accordance with the orbital movement of the spacecraft, and in accordance with the cosmonaut's control inputs.

During the training sessions on the spacecraft simulator, the cosmonauts developed skills in inspecting and checking the equipment, spacecraft manual orientation, radio communications, use of the life support systems, conduct of the scientific experiments, filling out the flight log, and so on, and also the operations involved in the automatic re-entry mode. They also worked out their actions during unusual and emergency flight conditions (failure of various systems, communications failure, loss of cabin pressure, manual re-entry, and so on).

The exercises in the spacecraft simulator were carried out after the cosmonauts had completed a preliminary course of theoretical preparation and a series of training sessions on the functional trainers, where they developed their skills in use of the communications facilities and operation of the various spacecraft systems.

The final stage in the professional preparation of the cosmonauts was the conduct of a combined training session in the spacecraft simulator, when the flight plan was "run through" in real time up to periods of several days with operation of the actual life support systems (regeneration, conditioning, in-flight food, systems, and so on). During this training session, the environment was made as close as possible to that of the actual flight, except for simulation of the load factors and weightnessness.

The training session in the spacecraft simulator was supported by a team which included the team leader, human engineering instructor, medical psychologist, engineers, and simulator servicing technicians.

The operation of this team was guided by a procedural plan which included the exercises, the conditions for their performance, and standards for evaluating performance. In preparation for the Vostok flights, several exercises were used to work out the simpler elements of the flight task and then transition to "run through" of the entire multi-orbit flight.

During the training sessions, the instructor and the medical /59
psychologist watched carefully to make certain the cosmonauts'

actions were correct. This was possible because of the fact that all the onboard equipment was duplicated on the instructor's console, which made possible simultaneous monitoring of the actions of the subject with variation of the instrument readings.

The instructor could change the flight program at will, "create" various situations, including emergency situations, and see how the cosmonaut reacts to a particular "input", whether he takes the proper actions and how quickly he performs these actions. At the same time the medical psychologist observed the facial expressions and voice intonation (the cosmonaut's speech was recorded on tape, which then permitted special analysis), and in the case when the physiological functions were recorded make it possible to observe the pulse rate, respiration rate, and other vegetative reactions.

In the first training sessions the cosmonauts familiarized themselves with the spacecraft cabin, arrangment of the instruments and equipment, studied the normal instrument indications and their possible deviations. They found out precisely what happens in a particular system when the switches and other control organs are activated and deactivated. Then the cosmonauts practiced inspection and checkout of the equipment which is operable during launch, in orbital flight, and during re-entry in accordance with the control and operating instructions.

Each training session was conducted in the following sequence. The plan to be followed in the exercise was formulated, the plan was modified as necessary, and the flight log was filled out. Then the cosmonaut donned his pressure suit. After finishing the preparations for performing the exercise he reported that he was ready and sat down in the spacecraft seat. The training sessions were organized following the principle: everything should be as realistic as possible.

The cosmonaut established radio communications and checked out the equipment in the cabin. The usual aircraft rule was used as a basis for the check: left to right, top to bottom, in order to prevent omissions. After completing the inspection, the cosmonaut reported his results, his condition, and readiness for launch.

In his reports he observed the standard format in order to ensure clarity of the radio communications. In addition to the standard reports, the cosmonauts practiced their "in-flight" reporting using a tape recorder.

Then the launch of the booster rocket was simulated, the operation of its stages was accompanied by the noise of the rocket engines, which was reproduced with the aid of a tape recorder and powerful speakers. After "reaching orbit and separating from the last stage," the cosmonaut acted in accordance with the instructions and in accordance with the flight plan. Initially, the exercises concerned with the cosmonaut's actions in one-orbit and two-orbit flight were performed. Then the exercises were made more complicated and exercises associated /60
with practicing the operations in an emergency situation and manual landing of the spacecraft were introduced into the flight plan.

After performing the exercises, the cosmonaut reported the completion and his errors which he had himself noted. Then the instructor and team leader commented on the exercise. The criteria for evaluating the performance of the exercise were the number and nature of the erroneous actions made in the course of the training sessions.

We have remarked previously that in conventional flight the cosmonaut always has sufficient time to perform any particular operation in controlling the spacecraft. The only exceptions are emergency situations and the operations involved in the manual landing mode. Therefore, it is quite understandable that the speed of performance of the work operations in the usual flight regime was not decisive in the evaluation of the exercise. The primary factor in the evaluation of the cosmonaut's actions was the efficiency of the performance of the elements of the exercise and the nature of the errors made. A cosmonaut who accomplished the flight plan well can obtain an "unsatisfactory" grade if he makes only a single incorrect action which in actual flight could lead to an accident. Such serious errors include activation of the deceleration engine with an altitude error of 180°. In place of deceleration and descent from orbit such an action would lead to increase of the velocity and transition of the ship into a higher orbit from which return to earth at the proper time would become impossible. Such grave errors occurred very seldom in the cosmonaut training program, and then only in performing the first exercises.

The evaluation of the skill level finally developed at the end of the training sessions was formulated from the general pattern and speed of work, the emotion displayed in performing the task, the cosmonaut's behavior during preliminary preparation, the nature of the errors made in performing the task, and also from the capability for self-criticism and understanding of the meaning of the errors made in the operation,and his report on the results of the task performance upon completing the exercise. A general evaluation was made on the basis of collective discussion of the data obtained by the human engineers and the medical psychologist.

The training carried out on the Voskhod and Soyuz spacecraft simulators did not differ fundamentally from that used on the Vostok spacecraft simulator. The only really new factor was the extensive use of specialized trainers for developing skills in using the airlock for exiting into open space under altitude chamber conditions, conduct of the spacecraft rendezvous and docking operations.

The trainers, the spacecraft simulator, and the technique developed made it possible to prepare the cosmonauts for controlling the spacecraft in flight and the conduct of a broad range of different scientific experiments.

Both the general patterns in the establishment of the professional skills and the patterns which depend on the individual characteristics of the cosmonaut were determined in the process of the training sessions. /61

One of the general psychological patterns which showed up in the cosmonaut training sessions on the spacecraft simulator is that they approach the performance of the exercises with great seriousness, interest, and sense of responsibility.

Another feature common to all the cosmonauts was that they all made various errors in the beginning of the training sessions on the spacecraft simulator, and these errors when progressively decreased in the process of performing the exercises. The typical erroneous operating actions with respect to the different elements of the flight task are illustrated by the following data on the number of errors made (in %):

Radio reports 30	Use of Globus instrument 10
Manual orientation. . 13	Actions in unusual flight conditions . 17
Equipment check prior to flight . . 17	Other 23

The most frequent errors were made by the cosmonauts in their radio reports. While performing the exercises they either did not report at all or very little on the instrument indications, activation and burnout of the rocket stages, their sensations in flight, leaving the earth's shadow, transmission of commands, appearance of signals on the annunciator panel, and so on. They often failed to mention the time prior to reporting.

In the beginning of the training sessions the cosmonauts made many errors in checking the equipment, and also in working with systems such as manual orientation and using the Globus instrument. The manual orientation system differed markedly from an airplane control system, while the Globus instrument was fundamentally new in its design. After four to eight training sessions, the number of errors in manual orientation decreased by a factor of two, and by the end of the training sessions they disappeared completely.

Some of the professional skills — ability to divide attention properly, ability to determine the spatial attitude of the vehicle, and others — acquired in flights in jet fighters (all the cosmonauts who flew on the Vostok vehicles except for V. V. Tereshkova had experience in flying jet fighters prior to joining the cosmonaut group) were of considerable help in speeding up the process of developing particular skills.

In those cases when the individuals being prepared for space flight did not have adequately developed spatial perception, it was necessary to carry out additional exercises in manual orientation, resorting to demonstration using a very small model of the spacecraft and a large training-type globe. This was helpful in developing the skills involved in orientation in outer space.

The instructor's comments on the errors and also the recognition of the errors by the cosmonauts themselves were of considerable importance in eliminating deficiencies during the training sessions. Knowledge of the results of the work in the trainer and understanding of the operating errors were also very important factors in successful formation of the skills. Without this, successful development of a skill becomes markedly more difficult, and at times even completely impossible. /62

Experience in preparing the cosmonauts on the simulator showed that initially the subjects did not notice many errors and deficiencies in their work. They did not note many deviations from the instruction requirements, could not monitor themselves precisely, both with regard to their actions and the results obtained. However, in the process of performing the exercises the self-monitoring ability continued to improve. While initially not noting serious errors, the cosmonauts then began to note in their actions in the training sessions operating errors which even the supervising human engineer did not notice. The speed of recognition of deficiencies in their operation also changed. Initially the deficiencies were noted only after careful analysis of the results of the exercise, later they were determined by the cosmonaut immediately after performing the particular operation, or even at the instant the operation was being performed.

Our observations showed that long breaks between training sessions led to increase of the erroneous actions by a factor of 1.5 to 2. For most of the cosmonauts interruptions of up to three months did not reduce the quality of the skills which had been acquired.

From this observation we can conclude that it will be necessary to install functional trainers aboard spacecraft which will be in flight for more than three to four months in order to maintain skills in controlling operations such as docking, landing on the earth and other planets.

It is typical that the changes in the systems of the Vostok spacecraft associated with the increasing complexity of the program from flight to flight, and with improvement of several of the systems led to an increase of the number of erroneous actions even with a well-formed skill level. The cosmonauts did not always acquire the new skill immediately and often made errors while acting correctly in relation to the previous conditions. An example is the elimination of activation of oxygen flow into the pressure suit to check the oxygen availability. After this equipment verification change the cosmonauts continued for some time to turn the oxygen on for the test. The reason for this was the influence of the previously developed habit. The cosmonauts who had developed the habit in accordance with the original instructions of using the communications facilities only through the console began to make frequent errors in that they did not use the button for 30-minute readiness for launch. However, they all developed the habit quite quickly.

Many such examples can be cited. On the one hand, they indicate the necessity for limiting as far as possible the spacecraft changes and, on the other hand, the need for developing firm habits in the process of repeating the exercises. /63

Pavlov pointed out that the central nervous system has a marked capability for reinforcement of habits, i.e., for the establishment of a stereotype. A well ingrained habit is a strong dynamic stereotype, and it is precisely its inertia which determines the interference phenomena, i.e., the negative transfer of a previous habit, into new conditions. In other words, the stronger the habit, the more difficult it is to alter the habit and replace it by another.

A dialectic contradiction thus arises. The necessity for developing a strong habit in the cosmonaut is in contradiction with improvements and creation of new spacecraft. For example, Komarov had mastered completely the skills in controlling the Vostok spacecraft when he was the backup for Popovich. In preparing for flight in the Voskhod spacecraft, which he performed successfully, he mastered the skills involved in controlling this ship. And for the third time he had to develop the skills in controlling the Soyuz-1 spacecraft, which differed significantly in its construction from the preceding ships.

Experience in preparing the cosmonauts showed that in resolving the contradiction — strong habit and design changes — it is necessary to develop flexible habits based on conscious mastery of the working operations and not on mechanical memorization. The more consciously the cosmonaut acquires habits and the faster the habits are developed, the longer they are retained, and they are found to be more flexible and economical. In preparing the cosmonauts it was also noted that flexibility of skills was influenced by their inclusion in a complex of actions which were more complicated in structure and their use in various situations for the solution of more difficult and complex problems.

The general pattern that developed in training the cosmonauts on the Vostok spacecraft simulator naturally did not exclude individual variety in the course of the training sessions and performance of the space flights.

The following guidelines were used in studying the individual psychological characteristics with regard to development of cosmonaut skills with respect to control of the spacecraft and its systems: the nature of the initial mastery of the task; repeatability of errors of the same type; relation between the rate and efficiency of the mastery of the task with normal conduct of the flight and under unusual flight conditions; relation between the errors associated with sequential performance of the flight task and concrete failures in individual operations; sequence of actions and reports on the actions performed; negative influence of breaks in training sessions on the quality of the skills. The individual psychological study technique included recording and analysis of the erroneous actions, observation of the emotional reactions, activity, self-criticism, initiative, and psychomotor activity while performing the experiments. /64

The objectivity of the evaluation of the individual psychological interpretation of the activity characteristics on the spacecraft simulator was also aided by comparing the behavior of the cosmonauts in the trainers with the general pattern of their behavior in everyday life and the nature of the psychological reactions during different forms of training sessions and tests (parachute jumps, centrifuge tests, isolation chamber tests, and so on). The basis used for the analysis was the principle of maximal exposure of the individual psychological capabilities of the subject in mastering complex operator skills, and not a dry, unrealistic collection of random errors and deficiencies.

In our observations the differences in the establishment of skills in control of the spacecraft and its systems were clearly determined as a function of the typological higher nervous activity characteristics.

The cosmonauts with choleric temperatent, for which the stimulation process dominated and relatively high mobility of the nerve processes was observed, mastered the professional skills rapidly. However, they were characterized by various errors in the beginning of the training sessions and a tendency to premature actions. They mastered the tasks, including the unusual flight cases, faster than conventional exercises. In the preliminary preparation, cosmonauts with such typological characteristics asked many questions and the details of the task were discussed actively. In the qualifying exercise on the spacecraft simulator they worked fast, showed initiative, reacted actively and emotionally to the situation. Characteristic errors for individuals of this type were haste and insufficient concentration of the attention. Their summary reports were clear, lively, expressive, sometimes insufficiently concrete and subjective.

Here is an example of a cosmonaut of this type. Cosmonaut S., a bouyant, happy individual with well-developed sense of humor. During the individual psychological study of the higher nervous activity in the preparation process, it was found that he had high nerve process force and mobility indices with slight dominance of the excitatory process. Piloting habits were developed quickly, few mistakes were made and they were not

characteristic; error repetition was not observed. The exercise with unusual situations in flight was mastered relatively faster than the normal flight version. The errors in the initial preparation period were primarily of the nature of premature actions. Long breaks in the skill development process had a negative effect. During the skill formation period he worked rapidly, /65
happily, showing initiative, and without errors. His summary report on the completed exercise was lively, objective, self-critical, and complete. His reports in the course of the training were concise and concrete.

In this case the nature of the skills formed and their formation reflect the typological characteristics of the cosmonaut's higher nervous activity, and also those character traits such as self-criticism, perseverance, and keenness of observation.

A striking representative of the sanguine type was Gagarin, who demonstrated throughout his preparation and training for flight a high degree of precision in performing various experimental psychological tasks, excellent interference resistance when subjected to sudden and strong stimuli. His reactions to "novelty" (state of weightlessness, extended exposure in the isolation chamber, parachute jumps, and other activities) were always active.

During the study in the isolation chamber, there was noted a highly developed capability to relax even in the short intervals set aside for resting, drop off to sleep rapidly, and wake up by himself at a set time. A notable characteristic was his sense of humor, tendency to joking, and good-naturedness.

During the training sessions on the spacecraft simulator, his characteristic traits were a quiet, confident style of work with clear and laconic reports after completing the exercise. Thoughtfulness, curiosity, and good-naturedness gave an individual pattern to the development of his professional skills.

A phlegmatic temperament is characteristic for individuals with well-balanced excitatory and inhibitory processes, but with relatively low mobility of the nerve processes. The cosmonauts with this type of higher nervous activity mastered the task over a longer period of time, repeating errors of the same type. They acted first and then reported. They did not note their own errors completely, particularly in the initial stage of development of the spacecraft simulator piloting skill. They mastered the normal flight version earlier and more thoroughly than the task with unusual flight conditions. During the preliminary preparation they asked few questions, but these questions were always to the point and helped refine important details. They worked quietly, accurately, unhurriedly. Their summary report was objective, detailed, and systematized. Their reports during the course of the exercise were basically of a stereotype nature. Characteristic for cosmonauts of this type is progressive reduction of the errors and improvement of their professional activity. Breaks in the training schedule had no effect on the development of their professional skills.

Here is an example of one of the cosmonauts with a phlegmatic temperament. With relatively low mobility and quite high force of the excitatory and inhibitory processes, the skills developed relatively slowly for this individual, there were /6 many errors, although of the same type, and they disappeared gradually. He mastered the exercise with the normal flight version rapidly. Characteristic of his work in the trainer were unhurriedness, concentration and accuracy, high emotional restraint, clear and laconic reports. Training breaks of more than six months had practically no effect on skill formation. His final report was informative and detailed. A high level of self-criticism was noted — he had observed most of the inaccuracies and errors in the training session.

There were no individuals with melancholy temperament among the cosmonauts. Psychological analysis of skill formation in the spacecraft simulator shows that the characteristics of skill establishment and their nature depend for the different cosmonauts on their individuality. Observations show that individuals with different type of higher nervous activity achieve equally high work levels, although the ways in which they master these skills are different for the different individuals. In spite of the marked features of individual variety, the skills which are finally formed ensure the performance of the "flight mission" and do not depend on the rate of mastery of the skills or the number of errors made in the training process.

However, we should emphasize here that all these skills were formed on trainers, and only experience can answer the question of the degree to which they correspond to the actual conditions in space flight. Experience shows that all the cosmonauts successfully operated the various spacecraft systems during the space flights, carried out the radio communications, and conducted the scientific experiments.

The fact that all the cosmonauts were able to "immediately" perform manual orientation of the spacecraft and carry out the docking and other maneuvers is explained by the correctly formulated education and training process.

During operations in the spacecraft simulator, the cosmonaut essentially "runs through" in his mind the possible deviations in spacecraft control in flight from the operation in the simulaor. Because of this, no subjective difficulties arise when controlling the spacecraft manually in space or when encountering various differences in the behavior of the ship from the behavior of the simulator. Transforming this into psychological language, we can say that the cosmonauts' action acceptor had a probabilistic structure and was not rigidly programmed.

Thus, the trainers, spacecraft simulators, and technique developed make it possible to prepare cosmonauts for spacecraft control in actual space flights.

CHAPTER 2

ORIENTATION OF MAN IN OUTER SPACE

In the philosophical sense, time and space are forms of the existence of matter. "In the world there is nothing other than moving matter," wrote Lenin, "and moving matter can only move in space and in time."[1] Space and time are equally objective, exist independently of consciousness, are eternal, infinite, and unbounded. At the same time, being different attributes of matter, they have their own special characteristics. Space has three dimensions, while time has only one. /67

The three-dimensional nature of space (for simplicity, we shall consider Euclidean space) is expressed by the fact that at any point we can draw three and only three mutually perpendicular straight lines. The position of any point is completely defined by indicating its three coordinates, i.e., the distances to the intersecting planes selected as the reference system. As for temporal one-dimensionality, it means that any instant of time, corresponding to the beginning, end, or intermediate stage of any process is defined by a single number, which expresses the time interval since some other moment, taken as the reference.

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[1] V. I. Lenin, Polnoye Sobraiye Sochineniy (Complete Collected Works, Vol. 18, p. 181.

In space we can displace bodies from right to left and from left to right, upward and downward, and so on. In time, however, all events flow only from the past through the present to the future. Time is irreversible, and in this it again differs from space.

The dialectic oneness and contradiction of space and time as attributes of matter also find their reflection in the sensory organization of man. On the one hand, the processes of perceiving space and time relationships are intimately interconnected and interdependent. On the other hand, we find that the two perception processes each exist in specific functional systems of the brain and are to a considerable degree differentiated. /68
This is conformed both in experiments and in numerous clinical observations of patients with skull wounds, tumors, and certain other brain ailments. The existence of such differentiation forms the basis for presentation of the space and time perception problems in individual chapters (although, naturally, we shall touch upon their interaction as well). However, before presenting the specific material it is advisable to discuss briefly the philosophical aspect of this problem, relating equally to space and time perception.

In "Materializm i empiriokrititsizm" (Materialism and Empiriocriticism) Lenin worte: "While time and space sensations can provide man with a biologically appropriate orientation, this can occur only if these sensations reflect objective reality outside of man; man could not have adapted biologically to the environment if his sensations had not given him an objectively correct representation of the environment."(2) It follows from this

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[2] V. I. Lenin, Complete Collected Works, Vol. 18, p. 185.

that the correct representation of objects is inextricably associated with adequate reflections of their space-time characteristics and relations. At the same time, in Lenin's review of Feuerbach's book "Lectures on the Essence of Religion", he notes the author's idea that man has just the number of sense organs "necessary to perceive the world in its unity and totality". In the margin of his review, Lenin posed the following question: "If man had more senses would he have discovered more things in the world?" Here is the answer: "No."(3) In other words, from the viewpoint of Marxist gnosiology, our sensory organization is sufficient for us to be able to reflect adequately the world surrounding us and recognize objective truth. However, prior to the space era this conclusion was based, so to speak, on purely earthly material.

F. Engels wrote: "Materialism will alter its form with each discovery which constitutes an epoch even in the field of natural history."(4) But the conquest of space is not just a single discovery, but rather a whole series of major discoveries in the most varied branches of scientific knowledge and applied sciences. The space activity of man is associated with utilization of all the very newest achievements of scientific and engineering progress and gives birth to scientific directions which have not been seen previously.

In this connection for the first time in history the possibility arises of confirming the laws and categories of materialistic dialectics by data from the sciences brought to life by space exploration. /69

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[3] V. I. Lenin, Complete Collected Works, Vol. 29, pp. 51-52.
[4] K. Marx and F. Englels, Sochineniya (Collected Works), Vol. 21, p. 266.

We know that all the living beings which inhabit our planet have developed under, and are constantly subjected to, the influence of several specific terrestrial factors. These include first of all the earth's atmosphere, daily and annual periodicity, definite magnetic and gravitational fields. If we consider, for example, the earth's gravitational force, its influence has shown up not only in several physiological functions, the size and structure of the animals, but also in the psychophysiological mechanisms of the reflection of the external world, including space and time relations. Thus, man's central nervous system, its structure and functions have developed and been consolidated as a result of long-term evolutionary development under specific terrestrial conditions and correspond to these conditions.

However, it is quite probable that under fundamentally different conditions of evolutionary development the sensory (and pschophysiological in general) organization of living beings, necessary for adequate reflection of reality, would be constructed differently. According to A. Ye. Magaram (1960, p. 59), Lenin in a conversation with him expressed the admissibility of the fact that life exists elsewhere and thinking creatures inhabit the other planets of the solar system and other places in the universe, and that — depending on the gravity force of the given planet and other conditions — these intelligent beings perceive the world with different sense organs.

The detailed resolution of such problems is a matter for the future, when with the development of cosmonautics and several other branches of science and technology it will be possible to study directly extraterrestrial forms of living organisms, and it will also be possible to make contact with extraterrestrial civilizations. At the present time, the emphasis is on the solution of a somewhat different problem, which is even today not only of great theoretical and ideological importance but also of tremendous practical value. The question is the following: to what degree and how will the psychophysical organization of terrestrial man ensure adequate reflection of reality, including space and time relationships, under the conditions of outer space, to which is is not historically adapted? The importance of obtaining an answer to this question is seen from the fact that even aviation practice includes numerous examples of flight accidents due to illusory perception by the pilot of spatial interrelationships of real objects, and also because of inappropriate temporal distribution of his actions in controlling the airplane.

Let us begin with a brief characterization of the psychophysiological mechanisms of spatial relationship perception by man under normal terrestrial conditions.

PSYCHOPHYSIOLOGICAL MECHANISMS OF SPATIAL ORIENTATION

By spatial orientation under the conditions of our planet, we mean the ability of man and animals to assess their attitude relative to the direction of gravity and relative to various surrounding objects. Both components of such orientation are functionally intimately related with one another. However, as Komendantov has correctly noted, their interactions are not unique. While the first component in many cases can be realized independently of the second, the second component is always based on the first. We can identify to some degree also the various psychophysiological mechanisms of spatial orientation in accordance with these two components of spatial orientation. /70

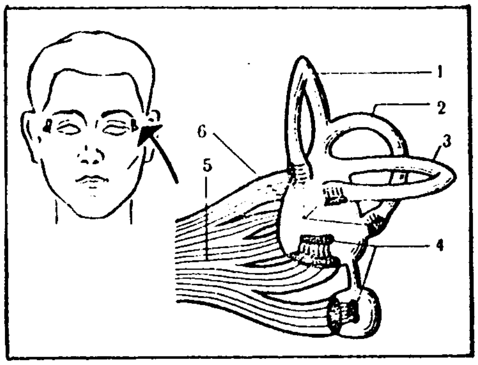
In light of the data of physiology and psychology, man's ability to perceive the attitude of his own body relative to the earth's surface and to perceive the location of external objects itself is not the result of specific activity on any single analyzer, but rather depends on the operation of a system of analyzers, including both exteroreceptors and interoreceptors.

Reflection of the body's spatial attitude relative to the earth's surface (first component of spatial orientation) at every moment is provided with the aid of the visual (optical), statokinetic (vestibular), proprioceptive (musculo-articular sensitivity), cutaneo-mechanical (tactile sensitivity), and interoceptive (sensitive terminations located in different internal organs — for example, the baroreceptors in the vessel walls) analyzers. Adequate stimuli for the corresponding receptors are: light energy for the optical ones, and mechanical energy for the others.

One of the basic analyzers in the system reflecting body attitude relative to the earth's surface is the vestibular analyzer. It is an integrated system consisting of the peripheral sensing apparatus, conducting nerves, and the central part with nuclei in the stem section of the brain and the cell segment in the hemispherical cortex. The sensing apparatus is subdivided in turn into the semicircular canals and the otolithic instrument, located in the temporal bone. The three semicircular canals are arranged in three mutually perpendicular planes and are filled with a fluid — endolymph. At the beginning of each canal, there are the "brushes" of the vestibular nerve sensitive terminations (Figure 8).

The idea of the importance of the semicircular canals in maintaining equilibrium of the animal's organism developed

Figure 8. Vestibular apparatus:
1, 2, 3 — semicircular canals (vertical, frontal, and horizontal); 4 — otoliths; 5 — vestibular nerve; 6 — sense hairs



after the experiments of Florence, who in 1824 after severing the semicircular canals of a pigeon first noted statokinetic disruption and head motions accompanied by vomiting. When the horizontal semicircular canal was severed, the pigeon's head performed motions in the direction of the damaged canal. This motion was not observed constantly, but upon further irritation of the place where the canal was cut or when the pigeon attempted to move, its head immediately began to oscillate. When the vertical (frontal) canal was cut, the pigeon performed involuntary forward movements of the entire body and head. When the rear canal was damaged, he tumbled backward and his head performed motions in the upward direction. This experiment initiated study of the semicircular canal role in statokinetic regulation (and not regulation of the hearing function, as was assumed at that time). /71

In 1878 the well-known St. Petersburg physiologist Ye. P. Tsion, who first explained the importance of the semicircular canals in the formation of human concepts of space, wrote that the semicircular canals are the peripheral space sense organs, i.e., the sensations caused by stimulation of the nerve terminations in the ampullae serve to form our concepts concerning the three space dimensions. The mechanism of these stimulations is associated with the laws of inertia. When the head is stationary or displaces rectilinearly and uniformly together with the body, the endolymph also remains stationary relative to the head. However, if the head is turned or tilted, the fluid in the corresponding canals begins to move in the direction opposite the turn or tilt. This causes stimulation of the vestibular nerve terminations and definite information on what is occurring arrives at the brain in the form of nerve impulses.

The otolithic instrument is in essence a gravitoreceptor, adapted to transmit information to the brain, primarily with changes in the gravity force. The principle of its operation is also quite simple. The bottom of the saccule is covered by neural sense cells, equipped with hairs, on which in a jelly- /72
like liquid there lie small crystals of calcium salts — the otoliths. Under the action of gravity, they press on the terminations and the neural impulse flux informs the brain of the pressure force. It is not difficult to understand that this pressure force will change with a rapid climb or descent. The resulting sensations are well known to people using high-speed elevators.

The experiments of Kreidel showed the great importance of the otolith instrument in animal orientation. He removed the otoliths from the otolithic instrument plane of a small crayfish and replaced with them iron filings. After this the animal maintained proper orientation in space and swam, as usual, spine up. However, if the experimentor brought a magnet near the crayfish, the posture of the animal immediately began to change in accordance with the lines of force of the magnetic field. If the magnet was moved downward, the crayfish turned over with his spine down, and if the magnet was moved to the side the crayfish would turn on his side.

V. M. Bekhterev related the orientation of the organism relative to the earth's surface (or the direction of gravity) very intimately with the equilibrium function. When performing any action, man is displaced in space, while retaining his equilibrium, and thereby his vertical posture relative to the earth's surface. It is true that in the case of any movement, change of posture, or physical work the location of the body center of gravity relative to the supporting plane changes, and therefore the stability conditions are disrupted. However, the disrupted equilibrium is restored by means of a compensating motion (for example, bending of the body, extending the arm to the side, and so on).

When walking, for example, man displaces his center of gravity actively over the supporting plane and sort of "catches up with" his outthrust leg. Thus, he selects the optimal motion regime to maintain equilibrium. This is also characteristic for all other forms of human activity associated with the necessity for taking a working posture and maintaining stability. Maintenance of equilibrium, even in those cases when an individual stands still without moving, is provided by continuous working of the muscles. The smaller the support area, the more work they must perform.

The cerebral regulation of the muscles participating in maintaining the posture is usually not perceived. The corresponding signals arrive at the cerebral cortex in generalized form if a fast reaction of the organism is required in the case of loss of equilibrium. In this case, the "command" to the particular muscle groups to equalize the body relative to the supporting surface in many cases is given before the individual realizes /73
what is happening. Thus, if a person slips on ice-covered ground with one foot and begins to fall in the direction of the

foot which has slipped, at that very instant the entire body tilts reflexively in the opposite direction, its center of gravity displaces, and equilibrium is re-established.

M. V. Lomonosov noted that man always tries to hold his body perpendicular to the earth's surface. "When the ocean rolls," he wrote, "every individual seeks his own perpendicular, specifically with his head." However, the Dutch physiologist Magnus was the first to discover the basic relations governing the regulation of posture — the attitude of the body in space.

The remarkable ability of the cat to quickly and correctly orient its body in space in order to land on its outstretched paws had long been known. Magnus showed experimentally that it is the reflexes from the otolithic instrument which determine the attitude of the cat's head in space during its fall (parietal bone upward), and it is the reflexes from the nerve terminations of the neck muscles which lead to the corresponding position with respect to the head and trunk. This mechanism, which regulates the motion of the animal during a fall, can be represented approximately as follows: the signals from the otolithic instrument determine the rotation of the head to the "parietal bone up" position, i.e., orientation of the head in a definite fashion with respect to the gravity force, after which it is the signals from the neck muscles which lead to change of the attitude of the trunk and extremities. This reflex act is accomplished by the motor apparatus, but the signal to "start" the latter are the stimuli from the vestibular apparatus.

Reflex regulation of the cat's posture during a fall is accomplished very rapidly. When falling from a height of only 50 - 70 cm, a cat lying on its back can turn over and "land" on its paws.

The vestibular analyzer is intimately related with the sight organ, whose role in spatial orientation we shall examine in more detail later. Thus, the indications of the vestibular and other analyzers are correlated with the indications from the visual sensations on the basis of the relationship between the direction of the gravity force vector and the line of the natural horizon. If a man with his eyes closed feels that his attitude in space is vertical, when the sight organs are activated the correctness of the gravitoreceptor indication is confirmed. This occurs hundreds of thousands of times in the course of his life, as a result of which strong conditioned reflex connections are formed.

The connection between the vestibular analyzer and the visual analyzer was convincingly demonstrated in the experiments of Purkinje, performed in 1820. Performing experiments on him- /74
self, he established the following: when turning with his eyes closed about the vertical axis to the right with his head in a vertical position, by placing his fingers on the lids of his closed eyes he sensed swinging motions of the eyeballs (nystagmus) in the opposite direction. When the rotation was suddenly stopped, Purkinje fell in the direction of rotation, and when he opened his eyes it seemed to him that objects moved to the right and he himself to the left. At the same time, he felt nausea, general weakness, and increased perspiration rate. He termed this state, which he was the first to note and describe, vertigo.

Purkinje was the first to study the sensory states during and after rotation. The term "tactile vertigo phenomenon" is associated with his name. This phenomenon amounts to the following. If the subject touches his foot to the floor during the time he senses counterrotation after stopping the chair in which we was rotating, he feels that he is dragging the foot in the direction of rotation sensation, i.e., the foot seems to move opposite the actual rotation. Purkinje also studied disruption of spatial perception of the surrounding situation after passing a galvanic current through the temporal bones.

In their turn, the sight organs affect the vestibular analyzer. This is illustrated, for example, by the following experiment. While viewing a panoramic movie, a pilot was seated in a chair with an unstable support, on which he balanced freely without losing his equilibrium prior to viewing the movie. His behavior was the same when the airplane appearing on the screen "flew" together with the viewer in level flight. However, when abrupt airplane maneuvers were shown, the pilot's equilibrium was quickly disrupted and he "tilted" together with the chair. We also know that some individuals watching a ship rolling on waves or similar pictures on a movie screen begin to experience a feeling of motion sickness, even to the point of nausea.

In the course of evolution, the earth's gravity played a definite role, not only in the formation of the supporting skeleton and musculature of living beings, but also in the development of the so-called muscle sense, i.e., proprioceptive sensitivity. Sechenov showed that the performance of any motor act would be impossible with the eyes closed without the musculo-articular sensations, which make it possible for man to interpret his posture relative to the earth's surface.

Tactile sensitivity also provides definite information on the change of body weight and posture in space. For example, when a man stands, the corresponding signals come from the skin of the feet; when he lies down, they come from the skin of the back, and so on.

The receptors which are located in the walls of the blood vessels and sense blood pressure are also "indicators" of the gravity force direction. When a man stands, the blood tends toward the lower-lying parts of the body and causes high stress in the lower extremity vessel walls, and a corresponding change of the information traveling to the brain. Other interoreceptors also signal a change of the gravity force direction. /75

The studies of B. G. Anan'yev, E. Sh. Ayrapet'yants and others have shown that the activity of the analyzers discussed above is synthesized by definite structures of the cerebral hemisphere cortex. As a result, a definite functional system is formed which reflects the situation as a whole, and thereby makes it possible to orient the body correctly in space relative to the gravity force. In general, the reflexes for maintaining posture in the vertical position are realized with the participation of the vestibular analyzer, musculo-articular sensitivity, and other receptors which counteract the action of gravity forces on the body mass. The solution of this problem is also associated with reflection in the consciousness of the so-called "body scheme", which includes concepts of the form, absolute and relative magnitude of the various parts of our organism, their interrelationships, possible motions of the extremities, and the general size and weight of the entire body.

We have already mentioned that the second component of spatial orientation, i.e., orientation relative to objects surrounding the individual, is always accomplished on the basis (background) of the first component. Such an orientation takes place with the aid of a special system of analyzers, which includes the optical, auditory, and chemical (olfactory) analyzers. Their receptors operate remotely. Having exceptionally high excitability to adequate stimuli, they are capable of differentiating sources of energy fluxes acting on them from sources acting at a great distance.

The leading analyzer in spatial orientation is the optical analyzer. In the process of evolutionary development, it has adapted to the reception of light reflected from various objects. One of the most important characteristics of the optical analyzer is that the sensations which arise during its activity are essentially projected into the external medium. Marx wrote: " . . . The optical action of an article on the optical nerve is perceived not as subjective stimulation of the optical nerve itself, but rather as the objective form of the article, which is located outside the eye."(5)

In this phenomenon A. N. Leont'yev sees a very important psychological fact, which is that "in the image we are given not our subjective states, but rather the objects themselves." Even those who are born blind and then have cataracts removed associate the optical stimulations with the external world. /76

"In this regard," wrote I. M. Sechenov, "it is very instructive to listen to the conversations of people blind from birth who have recovered their sight in adult years, when they see the surrounding world a few days after the operation. In spite of the fact that these individuals already had a clear picture in their minds of all the spatial concepts of the objects surrounding them, obtained through the sense of touch, the entire field of view seemed to them to be filled with a sort of continuous image which seemed to touch their eyes, and they were even afraid to move because of fear of running into one image or another."

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[5] K. Marx and F. Engels, Sochineniya (Works), Vol. 23, p. 82.

Vol. 1, p. 220, 1952.) The effect of "projection" of the optical image onto the objective world is a result of both the image striking the retina and the muscular and tactile sensations which the individual obtains in his exploration of the outside world in the course of life.

The perception of the shape, size and motion of an object and some properties of its surface is achieved by establishing complex functional systems of intra-analyzer (and also inter-analyzer) connections. For example, on the basis of only the image on the retina of the eye, we cannot yet judge the size of an object, since the dimensions of this image depend on the distance to the object. But vision at different distances is specifically provided by corresponding contraction (or relaxation) of the ocular muscles, which alter the shape of the crystalline lens and make it possible to focus the light rays passing through the lens properly on the retina. In the final analysis, judgment of the size of an object becomes possible as a result of establishing conditioned reflex connections between the retina and the eye muscles (more precisely, the accomodation muscles), i.e., between the sense and motor parts of the optical analyzer.

Depth perception is also provided by a change of the convergence (bringing together the optical axes of the eyes) as a function of distance. We know that differences in the images of external objects are obtained on the retina of each eye as a result of their different locations. As a result of the fact that the centers of projection of the two optical organs do not coincide but are separated by a gap, a particular point or detail of the images strikes the so-called disparate retina points rather than identical points. In the case of a high degree of disparity, the objects observed "double in the eyes". However, if the disparity does not exceed a definite magnitude, a sensation of depth develops which is considerably better than in the case of observations using only one eye.

Usually an individual does not perceive the sensations arriving at the brain from the accomodation and oculomotor muscles. These proprioceptive sensations can be quite clearly noted if /77
we look at our finger while slowly bringing it to our nose and then moving it away. In this case the musculomotor interoceptive stimulations associated with convergence and accomodation will arise.

B. G. Anan'yev quite rightly notes that perception of volume cannot be explained solely by the activity of the central portion of the optical analyzer (i.e., the corresponding segments of the hemispheric cortex). The essence of such perception is associated also with some sort of newly developing objective relationship between the receptor and the image on its object plane ("screen"). "It is obvious," writes Anan'yev, "that the optical sensation process, for example, not only begins in the eye but also terminates in the eye. This hypothesis requires recognition of the fact that the sense organ is not only a receptor but also an effector. We must also assume that there exists not only a forward (centripetal) but also a backward (centrifugal) connection between the receptor and the brain" (p. 52, 1961).

The feedback principle in analyzer operation had been discovered earlier by I. M. Sechenov. On the basis of three-dimensional vision, he showed that the optical apparatus of the eye is intimately connected with oculomotor organization. Moreover, Sechenov assigned great importance to the tactile sense in the development of three-dimensional representations. A complex dynamics of tactile and muscular sensitivity is always noted in the process of active palpation. Sechenov considered visual examination "entirely analogous in significance" to feeling an object with the hands. Developing this idea, Leon'tyev notes: "The movement realizing actual contact, 'real encounter' of the hand with an external object, must be subject to its properties. In feeling the object, the hand reproduces, following its outlines, its size and contour and by means of the signals coming from the motor apparatus forms a 'replica' in the brain." (p. 153, 1965).

The formation of conditioned reflex connections between hand palpation of objects and eye motion begins in early childhood. "The retina of the trained eye" is, properly speaking, the retina of an eye which has first studied under a hand. The child develops his three-dimensional vision ability on the basis of such conditioned reflex connections. Later on, man develops the ability to relate visual sensations and eye movements without the probing movements of his hands

We know that the yellow-spot region, where the receptor instruments are concentrated with maximum density, is the region which transmits the maximum information and realizes most clearly organized and differentiated vision. Therefore, to obtain the maximum information, the eye must take a position each time such that the retinal image of the examined portion of the object is on this central part of the retina. According to A. L. /78
Yarbus, when examining a particular figure the eyeball moves in jumps in accordance with the contour of the object. This motion is the most important component of visual perception. Each point of the contour, imaged on the periphery of the retina, serves as a stimulus signal which "drives" the eye to a position in which the region of best vision will be pointed at the contour line. Thus, to accomplish visual analysis, which involves continuous identification of the points carrying maximal

information and subsequent synthesis of these points, we need to have a system consisting of at least two stimulated points: one located at the periphery of the retina and serving as a source of those signals which stimulate further motion of the eye and have an orienting function, and another point located within the limits of the central part of the retina to receive and transmit differentiated visual information.

The clinical observations of A. R. Luriya, Ye. P. Pravdina-Vinarskaya, and A. L. Yarbus have shown that in those cases in which the existence of such a system of two simultaneously stimulated points is not possible (marked narrowing of the field of view, brain damage, and so on), there is disruption of the organized gazing motions and the visual perception process as a whole breaks down.

In accordance with Sechenov's ideas, Leont'yev describes the perceptive operation of the hand, like the eye, as a self-afferent process which is similar to the mechanism of servo devices which "adhere" to the object. "As a result of this, the hand running over the contour of an object does not leave the object and the eye does not get lost in individual elements of the object. Contact of the hand with the object defines the beginning and direction of its motion, which in turn determines further signals coming from the object; at the same time the feeling or examining process as a whole remains rigidly determined by the properties of the object." (Leont'yev, p. 172, 1965.) In its structure, this process represents a reflex ring. But this ring is closed only in the morphophysiological sense. Conversely, from the viewpoint of the reflection process, it is open at the "points of encounter" with the object. "Something similar takes place, for example, when a soft rubber innertube rolls freely across solid objects; it retains its ring-like structure and its characteristic type of rolling motion, but when it comes into contact with the objects it alters its configuration and thereby yields an adequate dynamic replica of them." (Leont'yev, p. 173, 1965.) In the course of tactile or visual reception a "replica" is also taken from the object. However, this is done not by altering the form of the "taking" substrate itself, but rather by altering the process: it is not /79 the probing hand or the examining eye which reproduces the "replica", but rather their motions.

At one time, V. M. Bekhterev suggested that not only the kinesthetic sensations from probing hand movements and eye motions, but also the maintenance of the vertical posture of man plays a major role in three-dimensional vision. Later A. A. Ukhtomskiy showed how the temporal connections between the general posture of the body in relation to the horizontal plane and the positioning of the eyes themselves are formed when changing the body attitude in space. For example, we know that tilting the head toward one shoulder leads to decreased accuracy in perceiving the location of a horizontal straight line. These studies were continued by Anan'yev. It was found that the vertical body posture, which is a result of the social and work experience of man, served as the primary basis for the development of such concepts as "up" and "down", "right" and "left", "forward" and "backward".

In general, psychophysiological studies have made it possible to find that, not only the spatial relationships of things surrounding man, but also the position of his body relative to the direction of the gravity force play an important role in the overall dynamics of three-dimensional vision. Ukhtomskiy's idea that vision is determined by a complex associative chain: vision-kinesthesia-vestibular sensations, has been confirmed.

The coordinates of man's field of view, the interaction of the monocular systems (i.e., of both eyes), and so on, are actually connected with the chain of visual-vestibular-kinesthetic reflexes.

We have mentioned previously that the hearing organ also plays a role in the analysis of spatial relationships. However, human capabilities in the field of direct auditory space perception are limited, and reduce basically to sound localization. The basis for this is the binaural effect, which involves sequential perception of sound acting on first one, and then the other ear. The olfactory analyzer has even less capability in localizing the source of an order.

Thus, human orientation in space is accomplished with the aid of several analyzers and those structures of the cerebral cortex which synthesize their activity into an integrated process of reflection of spatial relationships. Each of the analyzers reflects some aspect of that complex, combined stimulant which on the whole is what we perceive as the spatial characteristics of the surrounding world. However, the combined activity of several analyzers, representing the so-called functional pattern, acquires a new, higher quality, since it makes it possible to change from the reflection of individual aspects or properties of spatial relationships to their reflection as belonging to the object world. This makes it possible for man to respond to com- /80
plex stimulants, not by the sum of the individual reactions, but by an integrated activity which is a more advanced and therefore a more effective form of interaction of the organism with the ambient medium.

PSYCHIC REACTIONS IN THE WEIGHTLESS STATE

> They experienced blissful quiet and silence. The position and direction of their bodies in the rocket were indefinite — whatever they wished them to be.
>
> K. E. Tsiolkovskiy

K. E. Tsiolkovskiy suggested that under weightless conditions man may experience various illusions and disruption of his spatial orientation. However, he believed that it would be possible to adapt to even such unusual conditions. "However, these illusions, at least in the living quarters, should disappear in time," wrote Tsiolkovskiy.

From that time to the beginning of space flights, many ideas were expressed on how weightlessness can affect the status of the organism and psychic activity. Some foreign scientists even stated that weightlessness would lead to psychic reactions which are hazardous for the health, and that it would be completely impossible for man to exist under weightless conditions at all. Therefore, experiments were first conducted on animals using high-altitude rockets. Then the experiments were continued with men, but again not in space flight but rather during jet airplane flights along the Kepler ballistic curve to reproduce dynamic weightless briefly (from 20 to 60 seconds). A large amount of scientific data has now been accumulated in the Soviet Union and abroad on the influence of weightlessness on man's pschophysiological functions. It has been found that all the subjects can be divided into three basic groups.

The first group includes individuals who tolerate short-term weightlessness without any marked deterioration of their general condition, do not lose their ability to work in flight, and only experience a feeling of relaxation or relief as a result of loss of their own body weight. Gerathewohl wrote the following concerning his feelings in a state of short-term weightlessness: "In the course of my whole life, I actually had never experienced such a devilishly present state as I found under weightless conditions, and if someone offered me my choice of recreation I would take weightlessness for sure."

All the Soviet cosmonauts belonged to this first group. /81
To illustrate the sensations they experienced under weightless conditions, we shall present some recordings made after performing weightless flight in a two-seater airplane. "At the moment of transition to weightlessness, there is a feeling of great relief throughout the whole body, and this lasts from beginning to end." "Under weightless conditions I felt an amazing lightness of the entire body. My muscles were completely relaxed. A feeling of pleasant relaxation came over me." "When weightlessness was reproduced, I separated from the seat. My whole body was filled with a tremendous and at the same time pleasant lightness. I tried to take various articles by hand and 'place' them in space: I placed a pen and it floated freely in the cabin air" (Figures 9, 10).

After his first weightless flight, Yu. A. Gagarin wrote the following: "Prior to performing the 'hump', I was forced down into my seat. Then the seat moved away and my feet lifted off the floor. I looked at the instrument: it indicated weightlessness. There was a feeling of pleasant lightness. I tried moving my hands and head and everything was free and easy. I grabbed a pen floating in front of me and the oxygen regulator hose.... It was a pleasant sensation, where you put your foot, there it stays.... In general a sensation of lightness and freedom. There were no unpleasant sensations from the internal organs at all. I could orient myself normally in space. I looked at the sky, the earth, and the beautiful cumulus clouds. The instruments were easy to read. After the flight, my feelings were quite normal."

V. V. Tereshkova had the following to say about her subjective sensations during her first parabolic trajectory flight: "With the onset of weightlessness, there was a sensation of lightness; dust particles float about, raised arms are easily moved around in the air. Everything was very easy. I made notes during the second 'hump' during the weightless period. I felt fine, weightlessness does not lead to any unpleasant sensations for the organism. Weightless flight was pleasant. There were no visual disturbances or nausea...."

The second group includes individuals who experience during the weightless period illusions of falling, and also a feeling of turning over, rotation of the body in an indefinite attitude, being suspended with the head down, and so on. In the first 2 - 6 seconds, these phenomena are accompanied by anxiety, loss of orientation in space, and incorrect perception of the ambient situation and their own body. In many cases euphoria is observed (laughter, playful mood, forgetting the experimental program, and so on). For this group subsequent flights with reproduction of weightlessness do not lead to such marked sensations. Adaptation takes place.

As an example, we present the self-observation of one of the authors (V. I. Lebedev), made during the first weightless /82
flight in a flying laboratory airplane with a "swimming pool".

Figure 9. Cosmonaut V. M. Komarov in the weightless state

"Prior to the first 'hump' I sat in the seat, fastened in by the belts. From the engine sound and airplane vibration, I guessed that the airplane was accelerating prior to the 'hump' After a few seconds, the load factor increased and forced me into the seat. When weightlessness began, I felt as if I were falling into an abyss. I would estimate that this sensation lasted 1 - 2 seconds. My comrades 'floated' in front of my eyes. The parachute slowly floated up from under my seat and hung in the air. The positions of the people in the support-free state were unusual: some with their feet high, some on their sides, and so on. They moved around, tumbled, took unusual poses, pushed away from the floor, ceiling, walls and swam rapidly by in front of me. All seemed unusual and amusing. Being quite familiar with the theoretical sensations of weightlessness, I expected to have problems, but it turned out fine. This led to a feeling of pleasure, which transformed into euphoria. I gave a thumbs-up signal to my comrades to indicate that I felt fine. Then the weightlessness period was over, and the load factor increased again. After the hypergravity the euphoria continued until the beginning of the second weightless period.

"During the second 'hump' I was supposed to 'swim' in the weightless state. I put on the crash helmet and lay down on the floor, which was covered with a thick layer of porolon. The load factor increased, and I was forced down into the porolon. The weightless state occurred suddenly, and without a chance to collect my thoughts I felt myself flying upward and then in an indefinite direction. Complete disorientation in space took over. Then I began to analyze the situation to some degree. I began to perceive the floor and walls of the enclosure. It seemed that the latter was elongating rapidly. The illusion was reminiscent of the sensation when one looks in the wrong end of binoculars. I glanced at the floor and saw that it was moving below me, running away from me along with the elongating and foreshortening enclosure. At this time I tried to grab hold of something. But even though the objects below me and to the sides seemed quite close, I could not reach them with my hands, which caused a feeling of extreme emotional excitation. Then, finding myself in the aft end of the airplane, I grasped some object and stabilized my position in space." Complete adaptation took place in the subsequent flights. /83

Some of the subjects from this group showed disruption of perception of the "body scheme" in addition to disorientation in space. As an illustration, we cite the self-observation of a pilot flying an airplane under weightless conditions for the first time: "At 8 - 10 seconds after the onset of weightlessness I felt as if my head were beginning to swell and increase in dimensions. At about 13 seconds I had the impression of slow rotation of my body in an undefined direction. After 15 seconds I began to lose my spatial orientation, and therefore changed the airplane from the parabolic regime."

In this same group we encounter individuals who experience in the weightless state a feeling of so-called psychic alienation, psychic helplessness. Subject M, an experienced glider pilot, characterized his sensations in this situation as follows: "During the first seconds of weightlessness I felt that the airplane had rolled over and was flying in an inverted attitude, and that I was hanging head down in the airplane. I looked out the window, saw the earth's horizon, and realized that the sensation was false. After 5 - 10 seconds the illusion disappeared.

"During the time of the illusion and after its disappearance, throughout the entire weightless period I experienced an unnatural and helpless sensation which I had never experienced before and is difficult to characterize. It seemed to me that not only the situation in the airplane, but also something inside myself had changed. In order to avoid this unpleasant sensation, I tried to write during the weightless state and reach out with my hands to various objects. All this was done /84
without any particular difficulty. However, this feeling of helplessness and uncertainity did not pass and bothered me." (Observation by L. A. Kitayev-Smyk.)

In this observation there developed on the background of the space attitude illusions, which are characteristic for short-period weightless conditions, a feeling of "psychic helplessness" without any motor disorders or delirious interpretations. We believe that this state can be compared with the clinical symptom of "psychic alienation," when according to Megrabyan the patients view themselves and the ambient medium as foreign, unfamiliar, unusual, and at the same time, reasoning logically, they adjust and correctly re-establish in their consciousness the reality of the existing situation without, however, overcoming the morbid state in so doing. Such a state of psychic alienation then creates that category of depersonalization phenomena which, according to many psychiatrists, border on the psychic automatism syndrome.

The third group includes those individuals for whom spatial disorientation and illusions are more marked, last throughout the entire weightless period, and sometimess combine with rapid development of seasickness symptoms

This grouping is only a rough general scheme, within which individual investigators identify subgroups on the basis of other characteristics. Thus, Kitayev-Smyk identifies within the second and third groups two subgroups, depending on dominance of the illusion of falling, accompanied by disorientation in space and a feeling of fear, or the illusion of an inverted position of the body, being suspended head-down, and so on, while retaining a correct general understanding of one's attitude in space. For some representatives of the first subgroup of the third group, the illusions of falling under weightless conditions reach extreme degrees, accompanied by a feeling of fear, involuntary screams and marked increase of the motor activity. We (F. D. Gorbov, O. N. Kuznetsov, and V.I. Lebedev) have compared such a psychic reaction with the so-called "death of the world" symptom-complex encountered in several brain diseases. One manifestation of this symptom complex was described by A.S. Shmar'yan. For patient Sh. the attack begins with a severe headache and vertigo. This is followed by the onset of a definite falling sensation and the patient, if he can not grab hold of something, begins to experience "tumbling, as if he

were rolling down a hill." Thereafter, it seems to the patient that his body increased markedly in size. The surroundings also changed markedly in dimensions and outlines, buildings first got larger and then smaller, everything around him darkened, one building seemed to topple over onto another, everything became strange, unfamiliar, and foreign. Everything took place extremely fast, "faster than a spinning movie film," "everything collapsed and came to ruin," "like a storm all around." At this time the patient experienced marked fright, loneliness, alarm, withdrew from activities, and cried. Turning to his neighbor, he cried out: "I don't know about you, but I feel as if the end has come, everything on the earth is crumbling and falling apart, the end of the world has come," At this time the patient saw huge trees being uprooted in the distance, the entire earth was like a seething cauldron, as if from a volcanic eruption. Everyone died and the patient along with them. /86
All of nature also perished, "like the end of the world." This condition of the patient lasted for one or two minutes.

Here is an observation of Kitayev-Smyk on a subject during a brief weightless state: "During the flight, prior to the onset of weightlessness, he sat conversing in a relaxed fashion with the doctor. In the first seconds of weightlessness motor stimulation appeared, accompanied by "elevator" and "prehensile" reactions, an involuntary inarticulate exclamation, and a strange facial expression (lifted eyebrows, pupils expanded wide, mouth open, lower jaw dropped). This reaction was observed throughout the weightless period and prevented any contact between the subject and the doctor alongside him. After termination of the action of weightlessness, the described reaction disappeared, but the subject was in a moderately excited state until the end of the flight. After the flight, he had the following to say

Figure 10. Cosmonaut A. A. Leonov does a back flip, arching in the weightless state

about his experience: "I didn't realize that the weightless state was beginning. I suddenly had a feeling of precipitate falling and it seemed to be that everything around me was coming apart, toppling over, and flying in all directions. A feeling of terror came over me, and I did not realize what was going on around me." The subject remembered nothing of his reactions. When looking at the movie film taken of his behavior in weightlessness, he was quite amazed by what he saw."

We see that the "end of the world" symptom-complex is very reminiscent of the psychic reaction of certain individuals for whom disorientation in space, accompanied by a feeling of falling and terror, develops in the weightless state.

Also of interest for space psychology are the observations of neuropsychic patients when one of the symptoms of their /87 illness is a feeling of loss of weight of their own body. Thus, R.I. Meyerovich noted that patient B "often has a feeling of weightlessness — it seems to her that she is moving through the air"; patient S says that she "wakes up at night with a feeling that she is hanging in the air." Similar observations have been made by A.A. Mergabyan (patient Sh. reports: "Now I don't feel wither myself or my body, I seem to float through the air"; patient V says that "sometimes her body becomes light as a feather," that she "seems to be walking on air," and so on). The action of certain psychopharmacological substances presents a similar picture. For example, long before the space flights A.I. Sikorskiy observed a unique condition in the case of hashish poisoning, accompanied by a sensation of weightlessness and soaring upward. Many individuals also experience a weightless feeling when using LSD and mescaline.

The question obviously arises of whether or not there is hidden behind all these factors some general laws which will lead to an understanding of the mechanism of the development of unusual psychic states during weightlessness with disruption of the perception of the body scheme and disorientation in space.

It has been found that the onset of the "end of the world" symptom-complex and several other psychosensory disorders is caused by dysfunction, lack of coordination in the operation of the functional systems of the brain because of disease-related damage to the central nervous system. One cause of such dysfunction may be altered and distorted information coming from the sense organs. A typical example is Meniere's disease, named after the French doctor who discovered it in 1861. It proceeds as follows. An individual who is externally perfectly healthy begins to have periodically a feeling of a "blow" on his head. In this case he often falls to the ground, as if "struck by lightning," so fast that he cannot grasp hold of anything. At the same time noise appears in either ear and vertigo sets in. Some have the feeling that they themselves are turning and being thrown to one side, others feel that the surroundings spin in a circle (in the horizontal or vertical plane), that objects double and flicker, the floor earth, and bed displace under him and collapse into an abyss. In this case some patients lose their orientation in space completely.

It has been found that the ultimate cause of Meniere's disease lies in a periodic increase of the fluid pressure in the semicircular canals of the vestibular apparatus, which then leads to the appearance of unusual, distorted information coming to the brain from this sense organ. This situation has been confirmed by the experiments of Shtauder (cited by A.S. Shmar'yan), in which patients in a crepuscular state with feelings of euphoria and ecstasy had their vestibular apparatus stimulated from both sides experimentally, after which a state of dysphoria set in with feelings of catastrophy, disaster.

No less interesting is the experiment of L.P. Lobova in stimulating the vestibular apparatus by a caloric probe in a patient with schizophrenia. Under the influence of sharp vestibular stimulations, the patient lost his orientation, felt fear with an expression of dismay on his face, said that everything around him was being destroyed, falling apart.

Schilder in his work on hallucinations says that stimulation of the semicircular canals can not only affect optical perceptions, but can also cause visual hallucinations. He presents experimental data on the change in the visual hallucinations (appearance of /88 fanciful distortions, mobility, plurality) when stimulating the vestibular apparatus. In his fundamental study of hallucinations, Murg devotes a special chapter to the inter-relationships between the vestibular apparatus and optical hallucinations.

Together with Z.L. Kogan, we carried out the following experiment. After putting completely healthy subjects (six individuals) into a hypnotic sleep, we suggested that they see a narrow street with high buildings and a man standing in the middle of the street. After the appearance of the induced hallucinatory images, the vestibular apparatus was stimulated calorically. The subjects in the hypnotic state commented on the changes taking place with the hallucinatory images.

One of the subjects in the hypnotic state saw, as the vestibular apparatus was stimulated, how the figure of the man standing in the middle of the street "multiplied", and then they all began to whirl around him in a circle. Their faces were as similar to one another as if they were twins. The other subjects also noted various spatial changes in the hallucinatory formations. Thus, subject K noted, when the vestibular apparatus was stimulated, that the entire figure of the "man" stretched out and became like a figure in a "fun house."

In all probability the plurality and photographic similarity of the hallucinatory images when using the caloric probe, both in our experiment and in similar clinical observations, can be explained by the influence of the impulse pattern from the vestibular apparatus on the tonus of the eye musculature and by the nystagmoidal twitchings which sort of "rip" the hallucinatory image into parts.

In his study, Murg describes Grisman's experiment with cooling of the outer surface of the neck with ethyl chloride, which as a result of stimulation of the vestibular apparatus led to a slight tonic change of the eye muscles. In this case, the subjects noted a change of the visual perceptions in the form of motion and curvature of objects.

A series of experimental studies of Schilder and Goff confirms this same point of view, and shows that both the change in the perception of the objective world and the hallucinatory images is connected, on the one hand, with nystagmoidal twitching and, on the other hand, with the tonic changes taking place in the eye muscles under the influence of the vestibular simulations.

Thus, both the experimental data and clinical observations confirm that in many cases stimulation of the vestibular apparatus can lead to distortion of the perception of both actual reality and hallucinatory images.

Under weightless conditions, markedly changed and unusual information arrives at the brain, since the mechanical forces owing to terrestrial gravitation no longer act on the system of sense organs which perceive the spatial relationships.

The studies of Ye. M. Yuganov have shown that definite changes take place in the reciprocal relationships between the semicircular canals and the otolithic apparatus of the vestibular analyzer as a result of loss of weight of the otoliths. In this case, weightlessness does not lead to a functional disconnection of the otolithic apparatus, but shows up as an unusual "minus-stimulant." This leads to transmission to the brain of markedly altered information.

That information which comes to the brain from the pressure-sensing receptors of the skin, the subcutaneous cellular tissue, the baroreceptors of the cardiovascular system, and so on also /89 changes significantly during weightlessness. Since the muscular efforts which are necessary to maintain the vertical posture of the body on the earth become unnecessary under weightless conditions, the flow of the nerve impulses from the skin and skeletomuscular apparatus changes. This is shown by recordings of the bioelectric activity of the musculature under weightless conditions. The studies of Ye. M. Yuganov, I. I. Kas'yan, and B.F. Asyamov showed that the amplitude of the neck muscle biopotentials, equal to 130-180 μV in horizontal flight, decrease markedly (to 40-50 μV) under weightless conditions, and in many cases bioelectric "silence" is even observed. Similar changes were also observed in the bioelectric activity of the thigh flexor and extensor muscles. While in the initial state, this potential was 30-37 μV, in the weightless state, bioelectric "silence" was observed.

The electroencephalographic pattern indicates that weightlessness is a very strong and unusual stimulant. A decrease of the amplitude of the brain biopotentials accompanied by an increase of the frequency characteristics is observed in subjects participating for the first time in flights reproducing weightlessness. In other words, the stimulation process dominates in the central nervous system.

All the factors noted above lead to disruption of the systemic activity of the analyzers under weightless conditions. In certain individuals, this leads to all sorts of illusions concerning the attitude of their body in space, up to and including complete disorientation with loss of the correct perception of the outside world and the "body scheme." However, in those cases in which the nervous system quickly copes with such functional disharmony, as a result of which new interrelationships in the system of analyzers are rapidly established in /90 accordance with the altered situation, the individual may experience a feeling of pleasant lightness, floating, and does not lose his capacity for work. Consequently, for individuals with a weak type of nervous activity this information may cause disorientation in space and subjective sensations and behavioral reactions reminiscent of the "end of the world" symptom-complex.

As a rule, the reactions noted by the cosmonauts during weightless flights correlated with the reactions in other stressful situations. For example, sthenic emotions were noted in all the cosmonauts during parachute jumps.

The observations of G. Titov are of interest in light of the question of the effect of weightlessness on the appearance of unusual psychic states. During orbital flight, he developed unpleasant sensations which he characterized as a condition close to motion sickness and which were expressed in vertigo and nausea. When he turned his head abruptly, the vertigo intensified and and illusion of "floating" of objects appeared. Titov noted that not only turning of the head, but also flickering of objects ("passage of the earth") cause unpleasant sensations. These phenomena decreased when the cosmonaut took a comfortable posture and did not make quick head motions, decreased further after sleeping, and disappeared entirely after activating the retro rocket system. In spite of the signs of motion sickness, he did not encounter the phenomenon of disorientation, which is explained by his high indices of higher nervous activity and willpower.

We know from the report of Grissom, the American astronaut who flew in the Mercury program, that he experienced vertigo in the weightless state.

In a study by G.L. Komendantov and V.I. Kopanev titled, "Motion Sickness as a Problem of Space Medicine," flight conditions in the spacecraft are analyzed in considerable detail, and the mechanisms of the occurrence in the cosmonauts of what Lansberg calls "satellite sickness" are discussed as a version of motion sickness.

In this study it was suggested that "of great importance in the genesis of motion sickness is the condition of the higher nervous activity, in individuals of the strong type, motion sickness is observed more rarely, and when it does occur its manifestations are less marked. The converse is observed in individuals with a nervous system of the weak type" (1968, p. 333).

However, we should emphasize here that, even in individuals with a strong nervous system, for whom the vestibular proprioceptive stimulations when performing aerobatics are common occurrences, in cases of asthenization (exhaustion) severe disruptions of orientation in flight may develop, accompanied by emotional and neurotic breakdown. This is indicated, for example, by the following observation by Gorbov of pilot N. In the course of several years, N. carried out intensive flight instructional activity, but did not notice any excessive fatigue. His flight work received good grades. During the last two or three years, N. began to feel excessive fatigue, worked long hours, did not have normal rest. From time to time during night flights, he developed sensations of forced banking to the left, which he overcame by "willpower," forcing himself to "shake his head," concentrating on the instrument readings. He gave no particular importance to these illusions.

Once, while climbing out during a night flight N. entered a layer of clouds. Immediately after this he felt a sensation of false banking to the left. He did not change the flight conditions and the sensation eased off. Upon entering the hospital, the subject spoke more or less quietly about this. However, it was difficult to get an idea of what happened with him. Thereafter, since every time the discussion came around to the subsequent events N developed a marked affective reaction with crying, general tremor, and so on. However, it was finally found that all the remainder of the flight period was difficult for him, and the sensation of false banking continued. During the landing approach, N developed a troublesome and unconquerable sensation of forced change of posture and attitude of the airplane (inverted flight), which did not disappear even when the airfield came into sight. The subject experienced extreme physical tension and at the same time a feeling of sinking, falling, terror. He made the landing, "not recalling how...," exited from the airplane "soaking wet," hands and feet shaking, hardly able to walk. /91

In view of the protracted reactive neurosis (diagnosis: stable and marked asthenic-depressive state with affective instability, low spirits, hypochronditic fixations), N was declared unfit for flight operations.

Thus, comparison of the clinical descriptions of psychic disorders and the perceptive disorders observed in weightless flights and conventional flights shows many features of similarity between the two. The disruptions of the perception of surrounding space and self-perception which are caused in the case of weightlessness by inadequate adaptational capability are phenomenologically reminiscent of the psychosensory disruption phenomena in neuropsychic patients. The reason for this is the disharmony of the functional systems, although in individuals with a strong nervous system the perceptive disruptions usually do not reach complete disorientation. However, the psychic disturbances which arise under weightless conditions do have /92 several phases. In the first phase, the analyzer activity dissociation may be accompanied by slight and rapidly passing spatial illusions. The second phase is expressed by psycho-sensory reactions with disorientation in space and disruption of the "body scheme" perception, but with correct interpretation of the subject's own sensations. The third stage includes psychosensory disturbances with distortion of the perception of the surrounding situation and delirious interpretation.

ORIENTATION OF MAN IN OUTER SPACE

On the basis of general theoretical studies, K.E. Tsiolkovskiy suggested that the weightless state during space flight would lead to a change in the perception of surrounding space. In 1911, he wrote: "There is really no up and down in a rocket, because there is no relative gravity and a body left unsupported will not move toward any wall of the rocket; however, subjective sensations of up and down will still remain. We will sense up and down; however, their places will change with a change of the direction of our body in space. We consider up to be where our head is, and down where our feet are. Thus, if we turn our head toward our planet, it seems to us to be above us; when we turn our feet toward the earth we cause it to plunge into the depths, since it seems to be below us. The picture is grandiose and at first glance frightening; then we become used to it and actually forget the concept of up and down" (1947, p. 71).

The following experiments were conducted to study spatial orientation characteristics in the cosmonauts during brief periods of weightlessness, reproduced in a two-man jet airplane. The subject sat in the rear cockpit, seat and shoulder straps fastened. During the weightless segment of the flight, the pilot, banked up to 60-65° to the right or left. Prior to entry into the "hump" (prior to onset of weightlessness), the cosmonaut closed his eyes on command from the pilot and reported over the interphone his impressions of the spatial attitude of the airplane and the nature of the maneuver being performed. While in similar situations with their eyes open, the subjects did not record a single case of spatial disorientation; with the eyes closed all the subjects noted illusory perception of spatial relationships. None of the cosmonauts could determine the actual nature of the airplane maneuver. For example, V.M. Komarov wrote the following concerning his sensations: "Spatial orientation was difficult when the pilot performed a "hump" with a bank; it seemed to me that we were flying vertically upward."

This sort of disorientation is explained by the fact that under weightless conditions the information from the otolithic instrument is distorted, and the subjects lose their concept of their body attitude in space in relation to the earth's surface. However, as a result of tactile and musculo-articular sensations, they oriented themselves well with respect to the cockpit geometric shapes. /93

A large number of investigations to determine the excitability of the vestibular apparatus under the action of positive load factors and under weightless conditions were made by Ye. M. Yuganov (1965) and his colleagues. It was found that in the weightless state the nystagmus shortens, while in the case of positive and high gravity forces it becomes longer. The contraction of the nystagmus is explained by the change of the reciprocal influences from the otolith apparatus on the semicircular canals and vice versa. According to Yuganov, under conditions of positive and high load factors, the impulse pattern from the otoliths has a considerably less inhibiting action on the semicircular canal function than under earth conditions, as a result of which protraction of the nystagmus is observed. During the action of negative load factors and in the weightless state, the reverse relationships are noted. However, in concluding his article, the author felt it necessary to note that the problem of interaction between the otolithic and ampullar apparatuses is far from resolved. The interrelationships have been noted only in analysis of the vestibular-motor (nystagmus) reactions, and further investigations are required.

Since weightlessness theoretically has no effect on the inertial properties of the endolymph and therefore no effect on the nature and degree of the stimulation of the semicircular canals, there has been considerable interest in studying the sensitivity thresholds of the semicircular canals to acceleration under weightless conditions. In selecting the technique for conducting the corresponding studies, we (K. L. Khilov, I.A. Kolosov, V.I. Lebedev, I. F. Chekirda) started from the limited volume of the working area in the airplane cockpit and the limited experiment time. The experiments were conducted as follows. The subject was seated in a Barany chair, tilting his head forward 30° and closing his eyes (with a heavy bandage across his eyes). Then the chair was rotated through 180° in 20 seconds. If the subject did not notice the rotation, further rotations through 360° were made at intervals of three to five minutes in the course of 20 and 15 seconds. The acceleration sensitivity thresholds were determined only when initiating the motion; the sensations experienced by the subjects as the chair was stopped were ignored. At the moment, the subject senses rotation, he reports this to the doctor who records the time with a stopwatch. In certain cases electronystograms were recorded. As a reference, we used the /94 data obtained in level flight.

Under weightless conditions, rotation of the subject began five seconds after beginning of the weightless state at the rate for which the acceleration sensitivity thereshold had been determined for the subject in conventional flight. Tests were made with 11 males in the 23-45 age range with good tolerance for weightless flights, including three cosmonauts. Three individuals were tested once, five were tested twice in the course of the same flight, and six were tested from two to six times during two or three flights.

Analysis of the data obtained showed that the sensitivity of the horizontal semicirular canals to angular accelerations under conditions of dynamic weightlessness changed for all the subjects. This showed up in an increase of the length of time necessary for the appearance of sensitivity to rotation, In other words, the excitability of the receptor formations of the semicircular canals decreased under weightless conditions.

Thus, for subject V the threshold sensation in the horizontal flight segment occurred after 12 seconds at a rotation rate of one revolution in 20 seconds, while under weightless conditions the sensation had not been reached by this time. For the other subjects, the time of appearance of the feeling of rotation was extended by 3-11 seconds (on the average, by a factor of 1.7) in comparison with the baseline data. Here it was noted that the magnitude of this time extension did not change in the course of a single flight. However, in repeat flights there was a tendency toward a decrease by two to three seconds of the rotation duration required for onset of threshold sensation under weightless conditions.

We have noted previously that the absence of body weight in the weightless state is its primary specific effect. Considering from this viewpoint the dynamics of airplane flight along a Kepler parabolic curve, we must note that here we encounter the alternating influence of positive load factors and weightlessness on the organism as a whole, and specifically on the vestibular apparatus. On the one hand, prior to and after each weightless regime the weight of the otoliths is "increased" by several times as a result of the action of positive (head-seat) load factors, which leads to intensified pressure of the otoliths on their "spring supports" and the underlying hairs of the otolithic apparatus nerve cells. On the other hand, after 10-12 seconds this input disappears, giving way to the state of dynamic weightlessness. In this case, the otoliths "lose" their weight, which leads to removal of the otolith pressure on the nerve endings.

According to the theory of V.I. Voyachek and K. L. Knilov, in the case of the normal earth attraction force the otoliths have a continuous activating influence on the sensory and vegetative reflexes from the semicircular canals. We believe that the otolith "loss of weight" under weightless conditions leads to reduction of this influence, which then leads to increase of the sensitivity thresholds of the horizontal semicircular canals to angular accelerations. /95

In studying the role of the semicircular canals in spatial orientation of man under weightless conditions, we (V. I. Lebedev and I. F. Chekirda) conducted the following experiments. We mounted in a flying laboratory airplane a rotating chair in which the subject was seated with a blindfold over his eyes. The doctor-experimentor rotated the chair through a definite angle at a constant rate (one revolution in five seconds). The subject's task was to estimate the turning angle without changing his body posture (on the ground, in level flight, and under weightless conditions). Chair rotation under weightless conditions was started five seconds after initiation of weightlessness (with a total duration in each "hump" of 24-26 seconds).

In the first series of experiments we determined the possibility and accuracy of orientation for turns from 0 to 360°. In the second series the same determination was made in the same range of chair rotation angle change but during the fourth revolution. In the tests using the first version it was possible to make three measurements during a single weightless run. In the second version a single measurement was made in each weightless run. Half of the subjects were informed of the errors they made. In all we studied six males who had had experience in weightless flights and had good tolerance to this condition.

As a result of the experiments we found that the errors in determining the angle of rotation on the ground and in level flight are the same. They amounted to $\pm$ (10-20°) in the first series of tests and $\pm$(15-25°) in the second series. However, under weightless conditions the manitudes of the errors in determining the seat rotation angle increased markedly for all the subjects without exception. In the first series of tests the errors were minus 20-30° for a rotation of 90° and reached minus 35-70° for rotation from 180 to 360°. In the second series the underestimation of the actual rotation angle increased in individual cases to as much as 270°.

For the subjects who were not informed of the values of the true chair rotation angle the errors did not decrease in the repeat flights. For those subjects who were given these data the accuracy of the rotation angle determination increased from flight to flight, and quite significantly.

What is the reason behind all these phenomena? We have already noted that under weightless conditions there is an increase of the semicircular canal threshold of sensitivity to angular accelerations. This leads to a situation in which the central nervous system obtains from the corresponding receptors less stimulation when the subject is rotated through the same angle as in level flight. The result is underestimation of the rotation angle.

Voyachek found that rotation sensation depends not only on the acceleration magnitude but also on the acceleration action time (following the formula b·t, where b is acceleration, /96 t is action time). In our experiments rotation of the chair through a definite angle took place with the same acceleration during initiation and termination of the motion; the rotation time also remained constant. However, because of increase during weightlessness of the semicircular canal sensitivity threshold, the subjects sensed the initiation of rotation somewhat later than in level flight. For example, while in level flight the chair rotation initiation is sensed when it has rotated through 10^{o}, under weightless conditions this sensation appears only with rotation through $\pm$ (10-20^{o}). Thus, the rotation time interval was subjectively shortened for the subjects, and it appeared to them that chair rotation took place through a smaller angle than was actually the case.

Space perception is intimately related with time perception. Artificial separation of the study of space perception from time perception may be justified by the specific objectives of the study, but it does not correspond to reality. In space orientation the correct perception of the passage of time is of great importance, since when changing his posture man estimates not only the force of the stimuli but also the time of their action. As a result of these processes the individual develops an integral concept of motion in space and in time. In special investigations we found that for subjects with good tolerance to weightlessness a subjective speeding-up of the passage of time is noted. We shall return to this later on. For the present we simply note one more fact, which indicates that, in addition to increase of the threshold sensitivity, the subjective speedup of time passage (underestimation of the given time interval) also plays a definite role in underestimation of the chair rotation angle. While in the second series of tests the difference in the errors in comparison with the first series amounted in horizontal flight on the average to $\pm$ (15-25^{o}), under weightless conditions this difference increased to 20-30^{o}. This can be explained by the fact that the increase in the second series of tests of the rotation time under weightless conditions to 15-20 seconds led to considerable subjective understatement of the actual time interval. The subject, assuming for example that only 12 seconds had passed rather than 15 (which was actually the case), underestimated the chair rotation angle correspondingly.

Particularly interesting data on spatial orientation were obtained during the orbital flights. Thus, at the time of transition from positive load factor to weightlessness, Titov experienced an illusory feeling of head-down movement of his body. It seemed to him that the instrument panel shifted and occupied a location above the cosmonaut's head. Similar false sensations were experienced by the American astronaut Cooper. It seemed /97
to him that a tool bag had turned through 90° around his right hand. Other cosmonauts also experienced the overturning illusion with the onset of weightlessness. Gorbov associates this with continuation of the muscle support reaction in the new conditions. At the moment preceding weightlessness the acceleration forces (positive load factors) force the individual against his couch and muscular counter-support to the couch back is created. If the tension of these muscles is not released upon transition to weightlessness, a quite logical but still false feeling develops of flight on one's back or with the head down. However, if there is uniform muscular relaxation this feeling does not occur. There is also a hemodynamic theory which treats the illusion onset as the result of blood redistribution.

In the weightless state most of the cosmonauts, particularly when the spacecraft ports were covered by shutters, developed the psychological concept of "up" and "down" which had been acquired during the training sessions in the spacecraft trainer. This concept made it possible for them to orient themselves freely, both with their eyes open and closed. In the spacecraft cabin the individual not only visually "relies" on the instruments and objects surrounding him but also obtains a large amount of information directly by tactile sensitivity from the couch, the restraint system, and so on. When working with the spacecraft controls and systems, a significant information flow enters the brain from the skin and muscle receptors. All this makes it possible for the higher regulating mechanism of the brain to "cope" with the distorted information from the otolithic apparatus and accomplish the correct orientation in the environment. However, if these possibilities are not realized, the illusory impressions concerning the body attitude in space may be retained for a long time. For example, in the course of their orbital flight illusory sensations of this sort developed with Yegorov and Feoktistov. It seemed to one of them that he was in a half-bent-over position with his face down. The cosmonauts noted that the illusions occurred with their eyes both closed and open, and the nature of the illusions was the same in both cases. However, this condition was not distressing and did not interfere with their performance of the planned operations.

During their 14-day flight the American astronauts Borman and Lovell (4-18 December 1965) observed illusory sensations of an inverted position in the course of the first 24 hours.

For most of the Soviet cosmonauts the psychological impression of "up" and "down" respectively of the spacecraft cabin geometry with their eyes open was disrupted only in the case when they viewed in the porthole the stellar sky "below" and the earth's surface "above." This pattern was verified in the following experiment. In the flying-laboratory airplane a track made /98 of a special material was attached to the wall so that the subject could walk on this track in the weightless state. When walking on this track in the weightless condition, the impression is quickly created that this is not a wall but rather a floor and that "down" is below the feet. But this impression is quickly destroyed when looking out the airplane window and seeing the surface of the earth.

When orienting the spacecraft in orbital flight, the cosmonaut must have a clear impression of the spacecraft attitude relative to the earth's horizon and the direction in which the flight vehicle is traveling. Perceiving all this and including the spacecraft in his "body scheme," he begins to perform the maneuver. This is what Bykovskiy had to say about orienting the spacecraft in flight: "After engaging the manual orientation system I began to look for the earth. I looked out the portholes and in the Vzor sight. In the Vzor sight I glimpsed a small bit of the horizon off to the side. I quickly reasoned that the right hand porthole was up, toward the zenith. I deflected the controller to the right and released it before the pointer moved. The opposite pointer did not move. I immediately noted movement of the spacecraft. The ship continued forward at the residual rate. I think: "OK, that will save some fuel," and waited. The movement of the earth was just barely noticeable. I worked the same way about all three axes using the residual rates. When the angular velocity pointers moved, I released the controller and the opposite pointer did not move. What was particularly interesting in this orientation was that the ship followed the controls very well. I felt happy that everything was going so well. By determining the movement of the earth in the Vzor sight I oriented the ship in the landing attitude and used up only five atmospheres of pressure."

When exiting from the spacecraft into support-free space and transferring to another spacecraft, and also when performing assembly operations in orbit, it is necessary, in addition, to be able to orient oneself well in open outer space. Special experiments were conducted in the flying-laboratory airplane to verify how one can orient oneself in the support-free condition.

The cosmonauts were posed the following problem: after beginning to move along the "weightless pool," close the eyes for some time (5-10 seconds) and with vision "turned off" continue to determine one's attitude in space; then open the eyes and compare one's subjective spatial impressions in relation to the "pool" geometry with the actual situation. It was found that during the first 2-5 seconds of movement with the eyes closed the subjects, considering the rate of displacement and the sensations of their own rotation, could still realize correctly /99 what was happening, sometimes with large errors it is true. Thereafter this becomes more difficult for them. Thus, Nikolayev wrote the following in his report on this experiment: "After beginning the movement and closing my eyes, in the first 'hump' I estimated my attitude in space in the weightless condition by memory. I felt that in addition to the advance of my body along the 'pool' my body was rotating to the right. I thought that I should be about in the middle of the 'pool' and turned through 75-90°. When I opened my eyes I saw that I was actually near the right side of the airplane and turned through 180°, i.e., I was facing the ceiling.

"During the second 'hump' I did not open my eyes for about 10 seconds. After 4-6 seconds I could not mentally picture my location in the 'pool.' I lost my orientation. When I opened my eyes I was "suspended" upside down in the rear of the airplane."

It was just as difficult to determine with the eyes closed the spatial attitude of the body when rotating the body around the longitudinal axis during orbital flight (when free from the restraint system). It is interesting to note that in these experiments Popovich used the sound of an operating fan as a reference point in space.

When in the support-free state in the "swimming pool" of the flying-laboratory airplane or when "floating" above the couch in space flight, the test subjects and cosmonauts could touch the surrounding objects and spacecraft walls, which made it possible to relate the attitude of one's body in space with respect to these objects.

When leaving the spacecraft man encounters not only the support-free state but also "unoriented" space. Here the cosmonaut is connected with the spacecraft only by a flexible tether, which, it is true, is in some measure a supporting element, but in reduced form. In this situation all the tactile and musculo-articular sensations which arise from contact with the individual details and support areas in the capsule are missing. In open outer space the nerve impulses coming from the musculo-articular apparatus and the skin receptors do not provide any impressions of the spatial relations of the cosmonaut's body with the objects surrounding him, but rather yield only information on the inter-relationships between individual parts of the body, i.e., about the "body scheme," which includes also the pressure suit and the tether. Therefore, when the cosmonaut leaves the spacecraft his psychological impressions of his attitude relative to the capsule based on visual, tactile, and musculo-articular sensations are destroyed, and he must transfer to a completely new orientation, "relying" only on visual perceptions.

In preparing man for accomplishing the first sortie into open space, a coordinate system was initially recommended in which one of the "reference" points was to be the spacecraft with its longitudinal and lateral axes. In this system the /100 spacecraft was to be "down." This representation "matured" during the period of preparation for the flight. Several dozen schemes were sketched out, in which all possible versions of the attitude of the cosmonaut in support-free space were worked out relative to the spacecraft, Sun, and earth (Figure 11). The psychological impression that the spacecraft is "down" was refined and reinforced in special trainers and also during weightless flights in the flying-laboratory airplane. This impression was retained during the sortie into space from the actual space vehicle.

The following are the impressions of Leonov on his sortie into support-free and "unoriented" space: "Upon opening the outer hatch of the Voskhod-2 spacecraft airlock the unbounded cosmos appeared before me in all its indescribable beauty. The earth floated majestically by below my eyes and seemed flat; it was only the curvature along the edges that reminded me that it really is round. In spite of the quite dense light filter in the pressure helmet faceplate, I could see clouds, the surface of the Black Sea, the coastline, the Caucasus Mountains, and Novorossiysk Bay. After exiting the airlock and giving a light push, I separated from the spacecraft. The tether which attached me to the spacecraft and provided communications with the commander slowly stretched out to its full length. The small force exerted when pushing away from the spacecraft led to a slight angular displacement of the latter. The spacecraft rushing about the earth was bathed by the rays from the sun. There were no sharp contrasts of light and shadow observed, since the parts of the ship which were in the shadow were quite well illuminated by the sun's rays reflected from the earth. Majestic mountain ranges, rivers, and mountains floated past. The sensation was very much the same as in an airplane flying at high altitude. But because of the great distance it was not possible to pick out cities and relief details, and this created the impression that one was floating above a huge, richly painted map.

Here I was moving around a spacecraft traveling at cosmic speed above the rotating earth. I moved backward away from the spacecraft and approached it facing the ship, with my hands outstretched to prevent striking the ship with the helmet faceplate (or I "spread-eagled" above the spacecraft, like in a free fall above the earth when making a parachute jump). During the movement I oriented myself in space to the moving spacecraft and the "stationary" Sun, which was above my head or behind my back.

During one of the outward trips, as a result of imprecise pushoff from the spacecraft there was a complex rotation about the body's lateral and longitudinal axes. The unblinking stars began to float before my eyes on the background of the bottomless dark purple sky, with transition to velvety black. The view of the stars was replaced by a view of the earth and the Sun. The /102
Sun was very bright and seemed to be embedded in the blackness of the sky. The angular velocity soon decreased because of twisting of the tether. Although I could not see the spacecraft while I was rotating, my impression of my location was retained perfectly and disorientation was not observed.

In order to recall at every moment where the ship was located (when it was not visible), I had to sort of mentally plot my route with consideration for the angle at which I had left the ship and how many degrees I had turned. The complex of

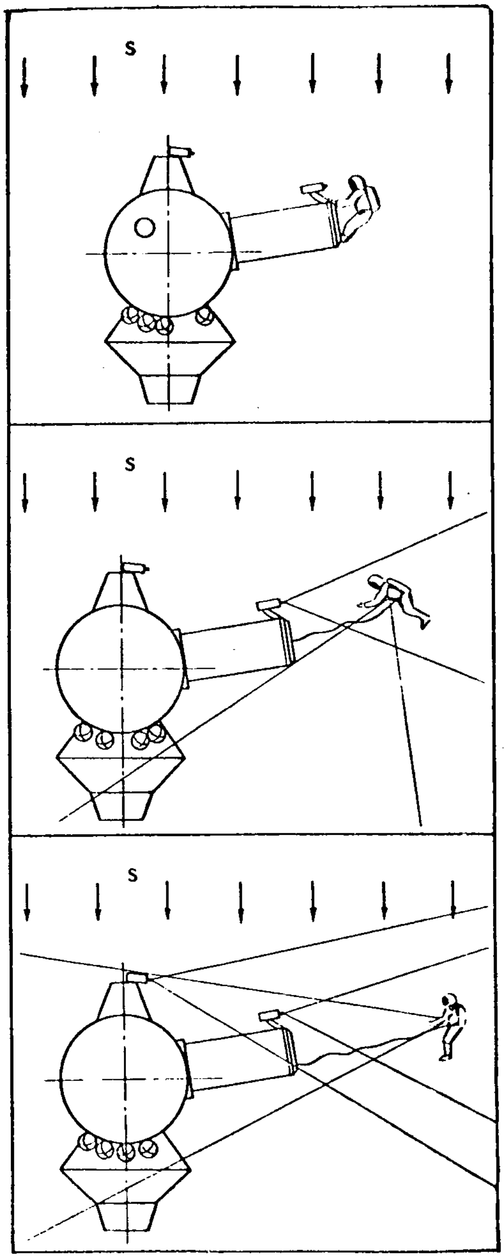

Figure 11. Drawings of A. A. Leonov in preparation for sortie into support-free space.

psychological impressions which made orientation possible included a mental picture of the geometric relationships between the heavenly bodies visible at the given moment (stars, Sun, earth) and the invisible spacecraft. Another good reference point was the tether, when it was fully stretched."

It should be noted that in spite of the numerous training sessions, complete automatization of the coordinate representations of space, in which the spacecraft is "down," was not achieved. However, the proposed orientation technique made it possible to carry out all the assigned tasks.

The experiment conducted by Leonov should be considered the first step into support-free cosmic space. In future flights, when manned spacecraft will travel from the earth to the other planets, and the cosmonauts with the aid of jet propulsion devices will sortie farther and farther into support-free space from their spacecraft, more complex problems of the formation of spatial representations in the new "reference" coordinate system will arise. In these cases it will be necessary to have not a single, but two or more coordinate representation systems with different "reference" coordinates, which presents major difficulties for the cosmonauts, since studies show that from one coordinate representation system to another is a complex psychological problem.

Thus, experience in orbital flights and sortie of the cosmonauts from the spacecraft into support-free space has shown that man can adapt to orientation under conditions which are very unusual for him. In so doing, relationships between the sense organs arise which are different from those on earth. Optical, tactile, and musculo-articular sensations become of primary importance, while the signals from the otolithic apparatus become less important. This new functional analyzer system is less stable in comparison with the natural system, which has been developed in the course of the protracted evolutionary development of the organism.

Since the optical analyzer plays the primary role in spatial orientation under space-flight conditions, it is advisable to examine in more detail the characteristics of optical perception in outer space.

VISION IN SPACE /103

In the preceding section we have established that under weightless conditions, particularly in support-free space, none of the indications of the sense organs other then sight can normally yield valid information for orientation in space far away from the earth. This is understandable if we recall that all the receptors with which we are familiar were obviously developed under the influence of only terrestrial factors and only the eye developed as a result of the direct influence of space factors as well. S. I. Vavilov has very aptly termed the human eye a "solar" organ, in the sense that it has been created, in addition to all else, by adaptation of the organisms to the vitally important solar rays coming from space. And it is these optical sensations and perceptions which had become the basis of the study of the Universe long before the space flights.

The most important vision characteristics are the acuity and resolving capability of the eye, and also its converging and accomodational capabilities. It is these properties of the vision organs which make it possible to differentiate light signals of different colors, read the indications of instruments, perceive spatial relationships in three dimensions, and so on.

We know from aviation psychology that most erroneous pilot actions (three quarters, according to Stevens) depend on malfunctions in the operation of the optical analyzer. Experience in exploring outer space shows that the range of problems solved by the cosmonauts with the aid of the optical organs is expanding and becoming more complex from one flight to another. However, it is well known that cosmonaut activity takes place under conditions different from those to which pilots are exposed. This is why the problem of studying the characteristics of optical organ operation in outer space takes on such great importance. The changes of the optical parameters under the influence of the unfavorable factors of space flight are being interpreted not only by physiologists and psychologists but also by the spacecraft designers, who need to know what functions man can perform in flight as an operator and, depending on this, which of these functions should be transferred to technical devices (radars and so on) and which should be left to man.

Prior to flights into space many hypotheses were suggested, which reduced basically to the fact that the absence of gravity in orbital flight causes some degree of deformation of the eyeball, and this in turn affects in some way the functional capabilities of the eye. It was suggested that the oculomotor apparatus, which has adapted to operate under conditions of the normal gravity force, will to one degree or another lose the motion coordination which had been developed in the process of life on the earth. And this will also affect depth perception, the accomodational and other functions of the eye. It was not clear how the liquid and semiliquid media of the eye would behave under weightless conditions. All these questions, /104
at least partially, had to be resolved prior to manned flights into space.

Studies of vision organ operation under weightless conditions were initiated during weightless flights in jet airplanes. In this regard the studies made under conditions of short-lived weightlessness by Kitayev-Smyk are of considerable interest. When questioned, he stated that most subjects did not note any visual perception changes under weightless conditions. However, some of them remarked: "In the beginning of the weightless period I did not see anything," "during weightlessness everything turned white and became blurred," "everything moved downward," "during weightlessness I saw only that object at which I was looking, everything else disappeared."

In one series of experiments the subjects were to examine in the weightless condition figures (circle, square, and so on) drawn on a large sheet of white paper. In another series the subjects observed luminous figures in complete darkness. In both cases it seemed to many of the subjects that the images grew, became pale, displaced downward, rocked from side to side. If the subject began to stare intently at some particular part of the figure, this part stopped moving and diffusing; it contracted to the normal dimensions but became very bright. The other portions of the figure behaved as before. As a result the entire figure became distorted: the circle became an ellipse, the square became pear-shaped, and straight lines became curved. When the experiment was conducted in complete darkness some subjects seemed to see a broad violet halo.

What is the mechanism of such illusions? At the present time we can give only a preliminary answer to this question. Examining the mechanism of the apparent growth of the figures, Kitayev-Smyk suggested the following hypothesis: "Under weightless conditions the force of the muscles which spread the eyes decreases and as a result the eyes converge to the nose — so-called convergence develops. However, as a rule an individual fixes his gaze on a definite object (in the present case on the image of the geometric figure). And in order that the object remain in the field of view the muscles which prevent convergence of the eyes will automatically tense up. In this case feedback immediately comes into play; the muscles signal the brain concerning this additional effort. The brain processes the signal and as a result the individual thinks: the visible figure either has broadened or moved farther away (under normal conditions this muscle tension is associated only with broadening or moving away of an object). But the second condition — marked increase of the distance to the object — would be possible only if the airplane cabin wall were to suddenly move back. The subject knows very well that this cannot occur. Therefore, common sense corrects the information received; only the first possibility reaches the individual — "the figure broadened."

However, we note that under weightless conditions some individuals develop illusions of increasing distance. For example, it seemed to pilot M in one of his first flights along the Kepler ballistic trajectory curve that the "pool" became longer. The pilot Stallings noted spatial illusions of increasing distance of the airplane control organs under weightless conditions. He wrote: "Initially I developed some erroneous sensations during weightlessness, as if I had to stretch in order to reach the various controls."

According to Kitayev-Smyk, vision disturbances during brief periods of weightlessness usually develop only at the beginning and decrease toward the end of the experiment. And after several flights the illusions disappear, adaptation to the changed conditions takes place.

Studies by American scientists have shown that visual acuity under brief weightless conditions decreases on the average by 6%.

Studies made on Soviet cosmonauts have not shown this pattern. It is true that these studies were made when the cosmonauts already had some "flight time" under weightless conditions.

Of particular interest are the reports of the first cosmonauts on their visual perceptions when performing space flights.

Both the Soviet and American cosmonauts noted in their reports that such rivers as the Volga, Amazon, and Nile, major highways, landing strips, ships at sea, and airplane condensation trails, can be identified from an altitude of 200-300 km. From the porthole of the Voskhod-2 spacecraft Belyayev observed an artificial earth satellite passing by at about the same altitude.

We mentioned previously that the size of the image on the retina, tension of the eye muscles, accomodation and convergence, disparity of the left and right images — all these are important elements of those processes which permit perception of distance, three-dimensionality, size, and shape of objects. However, studies have shown, for example, that accomodation acts at distances only up to 25 meters, and convergence up to 300-350 meters. Beyond these limits the perception of size and remoteness is based on certain indirect characteristics: comparison with other objects whose dimensions are known, sharpness of the contours, and so on. /105

Conditions may arise in outer space when the cosmonaut will not be able to see either the earth or any other references. Such conditions have been called "unoriented vision." In this case visual perception effectiveness decreases and sometimes various illusory sensations develop.

Physiological optics has established that in the case of "unoriented vision" the eye is focused not for distant vision, but rather for perception of an object at a relatively short distance. In this connection the individual becomes effectively near-sighted. This leads to considerable loss of ability to estimate distance, which can in certain cases interfere with cosmonaut functioning. For example, during the flight of the American astronauts McDivitt and White in Gemini-4 they were assigned the task of rendezvous with the second stage of the booster rocket, determining visually the distance to the docking target. McDivitt determined the distance to the target as 120 meters while the actual distance was 600 meters. This is why spacecraft must be equipped with special locators to provide determination of the distance between the ship and the docking target, and also to measure their relative velocities.

No less interesting is another fact. The American astronaut Cooper reported that he saw buildings and other structures in Tibet during orbital flight with the unaided eye. However, calculations showed that the resolving power of man's eye does not permit identifying such objects from this altitude. The American investigators suggested that Cooper was having hallucinations.

Analyzing Cooper's report, we suggested that the astronaut had a recognition illusion due to insufficient information content of the stimuli. This hypothesis is confirmed to some degree by the following special experiment, using a different analyzer, it is true — the hearing analyzer.

Subject S was under isolation conditions in an isolation chamber. During the course of the experiment various sounds were transmitted into the chamber in partial and muffled form. The subject was supposed to report in real time all the sound phenomena perceived. In many cases when S knew what was going on outside (say, electrophysiological recording, special monitoring of tape recordings by servicing personnel after summary reports, and so on) he perceived quite accurately the noises and conversations in the control room. However, in circumstances when the situation was not clear to the subject, he made serious errors. Thus, S evaluated the meaning of a conversation incorrectly, did not recognize a voice, and thought the noise of an electric motor operating in the control room was a tape recorder playback of a certain song being sung by Robertino Loretti. The subject was firmly convinced that his sensations were real.

We also evaluated this phenomenon under conditions of protracted isolation as a stimulus recognition illusion with inadequate informational characteristic for precise perception. The real-time reporting technique was of assistance in making the correct classification of the recognition illusion. Without real-time reporting S's sense illusions might have been classified as hallucinations. /107

For a more precise understanding of the mechanisms of the origin of these illusions, we must at least briefly examine the nature of the interrelation of man's sensory organization and the informative medium. According to Anan'yev, the composition and structure of sense reflection form the sensory organization, which depends on the individual's mode of life and activity. Depending on these factors, there is formed a definite interaction of the analyzers, their coordination, and relative domination of each of the analyzers. In addition to the general species characteristic, man's sensory organization has individual features which depend on the inherent anatomical and physiological peculiarities of the analyzers, on the concrete activity experience, on the entire ensemble of influence of the conditions of the social interrelationships into which the given individual enters.

The sense organs of a living being are not windows for the reception of just any arbitrary information, but rather extremely delicate instruments for continuous tracking, investigation, and selection of the essential phenomena in the outside world. The incoming signals fall not on the clean slate of our perceptions but rather on a prepared program of reception and reaction.

The path followed by the information arriving from the surrounding medium until its inclusion in the general behavior of an individual can be represented schematically as follows. An individual, orienting himself in reality, makes purposeful use of the information coming from outside on the basis of the capability of his sensory organization to analyze the coded-signal characteristics of the surrounding medium. The information coming to the brain from the sense organs is compared with the information stored in the memory. As expressed by Zinchenko, the untrained sensory system when receiving a huge amount of information remains blind, since it does not have criteria for separating the useful signals from the noise. Using the words of Leont'yev, the reflection process is therefore the "result not of action but rather of interaction, i.e., the result of processes proceeding essentially in opposition to one another. One of them is the process of action of the object on the living system, the other is the activity of the system itself with respect to the influencing object. This latter process, thanks to its similarity to the independent properties of reality, <u>includes in itself its reflection</u>" (1966, p. 53).

In those cases in which the informational characteristic of the object is not adequate, the "comparison" process proceeds by means of probabilistic "construction" with exteriorization of its representations corresponding to the assumed object. In many cases the image which arises as a result of "inadequate" interaction of the exteriorized representation with the stimuli being received may not correspond to the real object, but is subjectively identified with it. In these cases the individual /108 becomes convinced of the validity of the perceived information.

Thus we see that the cosmonauts' reports are based on integral perception, which is made up from operation of both the peripheral segment of the optical analyzer — the eye — and also the higher psychic functions (representation and so on). All this imposes some subjective imprint and makes it impossible to formulate exact data on the operation of the individual parts which constitute the optical analyzer. To solve practical questions associated with the inclusion of man in the spacecraft control system, we need more complete and objective data which will make it possible to evaluate the operation of both the eye itself and the functioning of the cortical segments of the optical analyzer. The corresponding studies were initiated with the second space flight. For example, during his orbital flight Titov had available optical instruments which permitted magnifying visible objects on the earth and thus he could verify the data obtained by the unaided eye.

Studies carried out by Akulinichev, Yemel'yanov, and Maksimov made it possible to evaluate the oculomotor activity of cosmonauts Nikolayev, Popovich, Bykovskiy, and Tereshkova during their first and second group flights. Special electrodes were attached on the left and right at the outside corners of the eyes to register the oculomotor activity. The signal from the electrodes passed through an amplification system to the spacecraft raiotelemetry system and was recorded by the ground stations.

In analyzing the oculogram the number of eye movements per minute, the amplitude, symmetry, and also the nature of the eye movement (slow, fast, nystagmoidal) were determined. Investigations by Maksimov and Boyko showed that in the case of constant eye movement velocity the recording of the eye motion velocity oculomotor activity by an ac amplifier yields the electrooculogram amplitude, which is proportional to the gaze shift angle.

In accordance with its magnitude (in microvolts), there were identified small-amplitude, medium-amplitude, and large-amplitude eye motions from the gaze center.

Analysis of the telemetered data showed that there is a stable increase of oculomotor activity for all the cosmonauts in the course of the flight. While under ground conditions when conducting tests in the Vostok spacecraft trainer, the number of eye motions did not exceed 40 per minute; in the first orbits of the flight the number reached 300-400 per minute in certain segments. The average number of motions also exceeded con- /109
siderably the values observed under normal conditions, and marked individual characteristics were noted among the cosmonauts. Thus, for Bykovskiy the average number of eye motions reached 90-110 motions per minute in the beginning of the flight while the number for Tereshkova was 40-70 (Figure 12).

Of interest is the fact that in the beginning of the flight large-amplitude motions dominated, which were often of the nature of "driving" of the eyes. As the flight continued, the eye motions became increasingly coordinated, faster, and

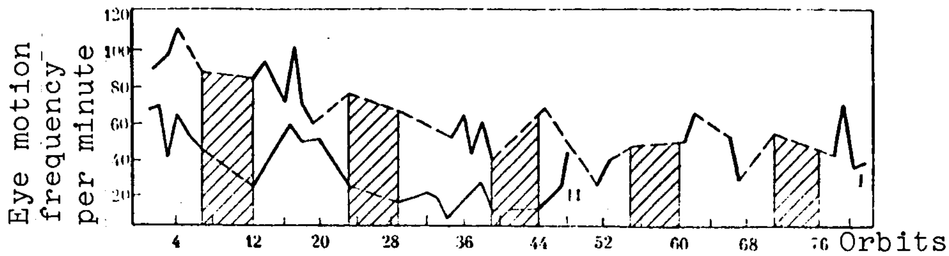

Figure 12. Variation of eye motion frequency for Bykovskiy (I) and Tereshkova (II) during group space flight (duration of each orbit about 90 minutes).

their frequency also decreased. In place of continuous oculomotor activity, on the elctrooculogram at the end of the first day of the flight there were recorded groups of rapid motions of varying amplitudes, and then individual motions. The reduction of the oculomotor activity by the second and third days was particularly marked. At this time the average eye motion frequency was in the range of 12-65 per minute. The eye motion frequency decreased sharply in the period prior to going to sleep and during sleep, so that individual movements were recorded on the electrooculogram and motions were entirely absent for several minutes.

We mentioned previously that the eye is intimately connected with the vestibular analyzer and stimulation of the latter's centers affects the oculomotor muscle tonus. The cosmonauts were assigned special vestibular experiments (tilting the head and trunk forward) during flight in order to study the effect of vestibular apparatus excitation on oculomotor activity. In this test Popovich's recording showed asymmetry of the oculomotor activity, which the authors believe was due to change of the functional condition and shifting of the eye muscle tonus. In this connection it is interesting to note that in the resting state Popovich did not observe during the flight any changes in the operation of the vestibular apparatus, but when tilting the head and trunk forward he developed sensations similar to those observed during rotation in the Barany chair on the ground.

During Tereshkova's 38th and 45th orbits, i.e., prior to going to sleep and shortly after awakening, brief nystagmoidal motions were recorded. The occurrence of the nystagmoidal motions just before going to sleep and shortly after waking up is probably explained by the fact that it is during these periods that the correcting actions of the higher sections of the central nervous system subcortical formation functioning become weakest. /110

Summarizing the data of these investigations, we can conclude that during three-to five-day orbital flights the cosmonauts did not suffer stable disruptions of eye motion coordination. The increase of the number of eye movements during the first orbits of a flight and also the occurrence of a brief change of the nature and asymmetry of the oculomotor reactions in Popovich and Tereshkova can be explained both by the direct effect of weightlessness on the oculomotor apparatus of the sight organs and also by the indirect effect through the vestibular apparatus. In explaining the oculomotor activity in the beginning of the flight we must also take into consideration the unusual nature of the situation and the emotional stress. These same factors obviously also explain the disruption of eye movement coordination, the occurrence of the so-called swimming motions or continuous "driving" of the eyes.

As adaptation to the unusual situation and weightless conditions takes place, the eye movements become more coordinated and faster, and then more infrequent as well. During the second and third days these movements approach in their nature the movements recorded during multi-day training sessions in the spacecraft trainer.

The study of the influence of extended weightlessness on the sight organs was continued during the Voskhod and Voshkod-2 flights. The program for these studies included methods for studying the resolution of the eye, the dynamics of visual operator work capacity, and the characteristics of perception by the individual of various objects and colors.

The use of conventional techniques for studying these functions was not possible, since they require large distances between the subjects and the special charts used, adequate illumination, and sometimes even cumbersome apparatus. In this connection V. Popov and N. Boyko developed and utilized special methods.

The standard Mir line charts, which were inserted into the flight logbook, were used to study the resolving capability of the eye in space flight. In all, 25 Mir charts with different line frequencies were used, which made it possible to determine visual acuity from 0.3 to 2.2 units. The charts were viewed from a distance of 300 mm. In addition, the visual acuity /111
of the Voskhod spacecraft crew commander V. M. Komarov was checked in flight with the aid of Landholt rings.

In order to exclude the influence of eye astigmatism on visual acuity, the Mir charts included four groups of lines whose directions were different. The cosmonaut's task included determination of that Mir set in which he could just barely but quite certainly differentiate the direction of the lines in all four groups.

It is well known that under space-flight conditions several factors in addition to weightlessness act on the individual. These investigations were also conducted prior to flight in the spacecraft trainer, where nearly all the space flight conditions except for weightlessness were simulated, in order to identify the influence of weightlessness. On this basis we established that those additional changes which were recorded in flight are basically the result of the effect on the organism of weightlessness and emotional factors.

In analyzing the optical resolution capability of the cosmonauts large deviations were obtained, even in the studies under spacecraft trainer conditions, in comparison with the data obtained in the laboratory, where optimal conditions for perception were created. These changes can in all probability be associated with the adaptational processes of the organism which finds itself in changed conditions of existence, and also by the different illumination in the spacecraft and in the laboratory.

One of the authors (Leonov) together with Belyayev took part in this scientific research study. We present the results on determination of visual acuity, obtained in the spacecraft trainer and under flight conditions (during the fifth and sixth orbits):

	Laboratory (5 measurements)	Spacecraft trainer (2 measurements)	Space flight (2 measurements)
A. A. Leonov.....	1.7	1.4	1.64
P. I. Belyayev...	1.7	—	1.34

We see from these data that the resolving capability of the optical analyzer changes only very slightly in a one-day flight. Since no study of visual acuity in the spacecraft trainer was made with Belyayev, it is difficult to explain the deterioration of his vision under flight conditions in comparison with the laboratory studies. A study of the visual acuity of cosmonauts Komarov, Feoktistov, and Yegorov also did not disclose any marked influence of the weightless state on visual acuity during flight of the Voskhod spacecraft.

The Mir charts were also used to determine the visual work capacity of the cosmonauts in flight. In this test the subject found one element of the chart in which he could count the number of lines at a distance of 300 mm. The quality of the visual operator work capacity was judged by the number of the Mir set with which the cosmonaut worked, the number of errors made, and the time spent on the test. Voluntary choice of the Mir chart element excluded the influence of visual acuity on the test results, since the cosmonaut in any case worked with a magnitude which was above his threshold, i.e., above the normal level under conventional conditions. /112

The change of cosmonaut performance in flight was evaluated on the basis of the ratio of the number of errors to the actual number of lines being counted. It is obvious that the time spent on the test and also the size of the lines selected for counting in relation to the eye's resolving capability threshold played a major role in the over-all characterization of visual operator activity.

The studies made aboard the Voskhod spacecraft showed some reduction of performance reliability for Yegorov (by 43%), while the comparable figure for Komarov was 25%. While Yegorov selected a Mir chart for counting of lines which exceeded his visual acuity threshold by 45%, Komarov used a chart which was only 20% above his threshold.

Visual work capacity was determined during the Voskhod spacecraft flight. The results of the experiments to determine the visual operator work capacity in the laboratory, spacecraft trainer, and in space flight for Leonov and Belyayev are summarized in Table 1.

TABLE 1

	Laboratory;			Spacecraft trainer;			Flight		
	Reliability, %	Test time, sec	Visual acuity	Reliability, %	Test time, sec	Visual acuity	Reliability, %	Test time, sec	Visual acuity
A. Leonov	100	36	0.95	88	60	1.1	75	90	1.2
P. Belyayev	100	43	1.17	—	—	—	80.0	—	1.06

We see from these data that the visual operator work capacity decreases somewhat in space flight. To find the reasons for this phenomenon (assuming that the resolving capability of the eye does not change under weightless conditions), we must examine the physiological mechanism of the visual operator work capacity when performing the task described above.

We mentioned in the first section of this chapter that in the process of examining stationary objects the human eye is in a state of rest (fixation) only a short time, after which the eye performs a whole series of jumps from one point of fixation to another. In counting the lines in the Mir chart the fixation change under terrestrial conditions takes place after about 1/60 of a second, and the duration of the fixation point change depends on the angle at which the points being observed are seen. If we examine points located at an angle of 1° (when working with the Mir charts), this time approaches 1/100 of a second, for an angle of 2° it approaches 2/100 of a second, and so on. When viewing two adjacent lines of the chart the cosmonaut fixes his view on a minimum of four points; when he shifts to the next line he fixes on four more points, and so on. Thus, the eye muscles receive a preprogrammed series of impulses with a repetition frequency of about one pulse per 1/100 of a second. "Under weightless conditions," write Ivanov, Popov, and Khachaturyants, "along with the general motion discoordination there is to some degree a loss of coordination of the oculomotor muscle group. Under weightless conditions the mass of the eye and its moments of inertia remain unchanged, but because of the loss of weight the friction in the mobile tissues of the eye decreases and therefore the force of the muscle group which must change the gaze fixation point becomes excessive, as a result of which the gaze "skips" the required point. A new adjustment of the eye is required and this is hard to accomplish in the given time segment, since after 0.01 second the next impulse arrives, strikes in the refractory phase period, and consequently /113 is skipped. Thus, it appears that the basic reason for the reliability decrease during visual operator work under weightless conditions is discoordination of the oculomotor apparatus. When counting larger details this does not occur, since the impulse repetition period increases sharply with increase of the resolution angle" (1968, p. 437).

During the Voskhod-2 spacecraft flight the cosmonauts were also posed the task of studying color perception inside the ship, for which a special chart was used. In this chart there were six different colored strips, arranged alongside black-to-white stepped wedges. We know that as the brightness is decreased all colors approach black. Therefore, the colors can be compared on the basis of this characteristic. For the study we selected the three primary colors — red, green, and blue — and the three complementary colors — cyan, magenta, and yellow. The cosmonauts were to find for each color that field of the black and white wedge which has the same brightness as the color in question.

The comparative results of control (or background) and in-flight studies performed in daylight made it possible for /114 Popov and Boyko to determine the differential changes in color perception. It was found that under weightless conditions the subjective brightness of the colors decreased markedly. The average decrease for all the colors exposed was 26.1% for Belyayev and 25% for Leonov. The largest deviations were observed in determining the magenta and cyan; there was somewhat less difference in determining red. The decrease for the other colored strips did not exceed 10%. Increase of the brightness was not noted in any case. The reason for the considerable decrease of the subjective brightness of the individual colors under weightless conditions is not yet clear, and its determination requires additional and more refined studies. However, the noted effect did not prevent Leonov from making several space landscape sketches during flight and also from memory.

These test results show that under weightless conditions the functional capabilities of the optical analyzer are subject to definite changes. To a considerable degree this applies to both the oculomotor function and visual operator work capacity. Visual acuity does not undergo any changes. But we should empasize that the problem of visual functions under space flight conditions need further study.

PSYCHOLOGICAL CHARACTERISTICS OF ORIENTATION BY INSTRUMENTS IN INTERPLANETARY FLIGHT

We have already established that of all the sense organs the most effective for orientation in outer space is the optical analyzer. Man uses vision to orient himself in the spacecraft and to perceive celestial bodies and other objects in outer space. However, the unaided eye becomes ineffective for orientation in interplanetary flight. Here special navigational instruments must be used, and this introduces significant changes in the activity of those psychophysiological systems which accomplish spatial orientation.

The change of the orientation process structure associated with the use of instruments was first noted in study of pilot activity. In conventional flight, as noted by B. S. Alyakrinskiy, vision permits the pilot not only to obtain information from the instruments located in the cockpit but also to accomplish quite long-range orientation from a "bird's eye view." The pilot must have a clear perception of surface reference points in order to construct correctly the flight regime. The point from which the pilot begins to create his orientation scheme lies outside the airplane, on the surface.

The situation changes markedly when shifting to piloting /115 by instruments. Here the center of orientation is psychologically transferred to the airplane cockpit. As Platonov emphasizes, the major factor is "mental skill in indirect and dynamic orientation." Under these conditions the individual judges his location in space not as a result of direct impressions from the natural and customary reference points, but rather with the aid of a system of technical devices which essentially "wedge in" between the pilot's or cosmonaut's sense organs and the real situation. Moreover, as we have said previously, the information coming to the pilot from the instruments is usually coded and the pilot is faced with the decoding task, which is usually not present during visual flight. However, the primary difficulty in decoding lies in the fact that the meaning of each individual signal can be understood only when it is compared with other signals. In other words, in the course of obtaining information during blind flight the individual pilot must not only quickly "read out" (i.e., correctly determine and decode the instrument indications) but also no less quickly correlate the arriving information into an integrated image of the flight vehicle attitude in space. In so doing the pilot's reaction to change of the situation is accomplished in accordance with the scheme "instrument-psychic image-motion." It is obvious that the process of indirect orientation requires considerable more time than does direct orientation.

However, as V. A. Sychev points out, as the pilot masters the skill of instrument flight, he begins to react in accordance with "instrument-motion" scheme. This conclusion is also confirmed by the data of Frantsev, Yegorov, and Kostyuk, who questioned 62 pilots flying modern airplanes. Of these pilots 47 had more than 1000 flight hours (experienced pilot group), and 15 had less than 500 hours (junior pilot group).

All the junior pilots questioned noted that when piloting, i.e., when maintaining a definite spatial attitude of the airplane, they transform the instrument indications into a psychic image of the airplane attitude, on the basis of which airplane control is then accomplished. Thus, pilot-third-class K, with a flight time of about 200 hours, reported that when flying by instruments an image of the spatial attitude of the airplane always develops; he essentially "sees" his airplane from the outside. After each control action he performs a mental and pictorial check.

In the experienced pilot group 44 individuals reported that when piloting they use only the instrument image and act in accordance with the "instrument-motion" scheme (only three individuals of this group noted that control is accomplished in accordance with the "instrument-image-motion" scheme). /116

During flights under actual instrument conditions they determine the airplane attitude abstractly from the instrument indications without the use of any image of the airplane or the position of its components.

This is also evidenced by analysis of human activity associated not with actual objects but rather with their replacements or images simulating them (Zinchenko, Leont'yev, and Panov).

The authors consider that if the operator is remote from the actual control of the object and must follow the indications of several instruments and react to their changes (as when maintaining the spatial attitude of an airplane), then he relates the instrument indication data directly with the required action. Under these conditions the operator has no need to mentally relate each time the instrument indications with the condition of the object being controlled. He need only learn by heart the possible instrument indications and those actions which he must make in response to the changes taking place. In this operating regime, to maintain the spatial attitude of the airplane the pilot essentially becomes like an automated control system — the autopilot, which is widely used in modern airplanes.

However, in those cases in which complications arise in flight, when performing an intentional maneuver (i.e., transition from "regulating" actions to "controlling" actions), the pilots again utilize a psychic image of the spatial attitude of the airplane.

This is how the test pilot M. L. Gallay describes this transition to the psychic image of the spatial attitude: "I picture how the pilot's eye moves from instrument to instrument during the course of this turn: bank angle, load factor, speed, rate of climb, heading, again bank angle, again speed..... Inertia forces his body into the seat. The ship shudders from the loads.... Beyond the cockpit windows covered with condensation there is dense white mist, but the pilot by his inner sight developed through years of flying sees that intricate curve, lying just at the edge of what is possible, which his machine describes."

This example shows graphically how the pilot on the basis of the instrument indication (information model) develops the psychic image (conceptual model) of the spatial attitude of the airplane. Only after the operator has constructed in his mind the conceptual model of the situation does he make a decision and accomplish the controlling actions.

As Zinchenko emphasizes, it is interesting here, first of all, that the pilot sees not so much the instruments as he does the flight trajectory, i.e., on the basis of the instrument /117
indications he creates a picture of the airplane's behavior. Second, this inner vision is developed after years of flying. In order to convert the indications of the individual instruments into the inner picture of the flight trajectory the pilot must perform a large number of complex information transformations. This is why it is very important in facilitating the work of operators controlling vehicles in space to create the "contact analogs" which we have mentioned in the preceding chapter.

It is interesting that in discussing flights, when the commander analyzes errors made by a particular pilot, all the pilots present, without exception, develop a clear image of the spatial attitude of the airplane.

When accomplishing dynamic orientation in flight the pilot must recall the corresponding information obtained in the recent past (i.e., he must have a good operative memory), and must also foresee his location in the near future. No less important is the fact that the pilot or cosmonaut, depending on the flight vehicle speed and the nature of the surrounding ambient situation, is forced to read the instrument indications and determine his spatial attitude at a rate which is imposed on him.

In general, the use of instrument indications introduces serious changes in the activity of those functional systems which perform spatial orientation. This also affects to one degree or another the activity of the entire central nervous system. It is obvious that the physiological systems which realize spatial orientation in blind flying include higher cortical levels (specifically the speech levels) than in orientation using natural references. The new functional system for reflecting spatial interrelationships which is formed is more complex than the conventional system.

However, since this system is created in the course of a comparatively short time interval, its stability is relatively low. Fatigue, and also the influence of other unfavorable factors on the human organism, can quickly disrupt this system and cause illusions (banking, turning, descent, inverted flight, and so on).

The physiological mechanisms of the illusions in blind flying in an airplane are varied. It is customary to divide the illusions into forms corresponding to the perception modes (optical, vestibular). Several illusions are associated with simultaneous participation in their formation of two or three analyzers (opticotactile, opticovestibular, and other illusions). The most detailed data on these problems is presented in studies of Platonov, Gorbov, Alykrinskiy, Derevyanko and others. Here /118
we shall simply emphasize the idea of Platonov that we "must not confuse the concepts of 'illusion in flight' and 'loss of orientation'". Loss of orientation in the case of an illusion may be caused not by disruption of the perceptions but rather by noncritical reasoning. However, an illusion, sometimes even a very marked one, may not lead to loss of orientation if the pilot relates critically to the illusion. "It seemed to me that I was

flying with a bank angle, but by looking at the instruments I knew that I was flying wings level," says the pilot in such cases. But the pilot need only lose his confidence in the instrument readings and he will lose his orientation" (1960, p. 166).

One of the measures directed toward prevention of illusions is development in the pilots of confidence in the instrument indications. When an illusion does develop the pilot is categorically forbidden to be guided in his activity by his sensations and is directed to control the airplane only on the basis of the instrument indications.

All that we have said in this section related to spatial orientation of the pilot using instruments during airplane flights. However, activity of this sort under orbital and interplanetary flight conditions has its own psychological specifics.

During orbital flights, just as in airplane flights, the cosmonauts can observe the surface of the earth, the Moon, Sun, and stars directly through the portholes or through the Vzor sight system. The cosmonauts can determine their location in space by the "passage" of the earth and recognition of surface objects. While during airplane flights the pilot must constantly orient himself relative to the horizon line, under near-earth space conditions there is no need for this. When orienting by means of the Globus instrument or a map, the cosmonaut projects his location on some segment of the surface of our planet without worrying about the attitude of his body and the spacecraft structure relative to the direction of flight and the horizon line. The need for solving problems of the latter type arises only when approaching a docking target, orienting the ship for landing, or when performing certain maneuvers (changing orbital inclination, orbital altitude, and so on).

Briefly speaking, in the orbital flight process the cosmonaut is always in a position to represent concrete segments of the earth's surface and trace the trajectory in relation to more or less concrete earth references. He can, for example, reason as follows: "Ten minutes ago I was over North Africa. Now I am above the Black Sea, and in ten minutes I will be passing the Ural Mountain region." Thus, we see that when performing an orbital space flight the cosmonaut, using instrument indications or making direct observations, constructs the space orientation /119 scheme "in earth fashion."

In contrast with orbital flights, interplanetary flights will take place not between two relatively stationary fixed points located on the earth but rather between two celestial bodies traveling in cosmic space with different velocities. Trips to the other planets will take not days or weeks but many months or years (for example, about five months to Venus, nine months to Mars, and so on). The cosmonauts cannot observe the earth's surface and orient themselves by particular areas of the earth. They will have to determine the location of the spacecraft from stars which are selected as "reference" stars in an entirely different, unusual coordinate system. Moreover, although the interplanetary voyagers will see constellations which are familiar on the earth, there will unfold before them an unusual stellar sky pattern, encompassing the luminaries of the entire celestial sphere and not simply the northern or southern hemispheres. Such a pattern has been observed by the American astronauts during their flights to the Moon. On the other hand, the celestial sphere will seem frozen in place — there will be an illusion of absence of motion of the spacecraft, reinforced by the complete quiet (except for the slight, uniform noise of the electronic instruments, which is hardly comparable, however, with the noise of operating propulsion engines).

In this situation the psychological difficulties in orientation by instruments increase markedly. The cosmonauts will be able to determine the flight trajectory (or check the corresponding information transmitted from ground observation stations) only by measuring with the aid of telescopes the angles of the "reference" celestial bodies and analysis of the results obtained using onboard electronic computers, which will then find the location of the spacecraft in the selected coordinate system. This position is expressed in some "abstract" point, which is not directly tied to any natural reference point. Nor is the calculated point at which the spacecraft must arrive at a given time easily visualized, since the flight trajectory is calculated with a lead angle and the planet serving as the trip objective is located at an entirely different point at the moment of calculation. To this we must add that it is not as easy for the cosmonauts as for the airplane pilot to correct the flight course. Space flight requires exceptional precision and timeliness of the reception and analysis of the navigational information. The very smallest error may lead to catastrophe and death of the cosmonauts.

Since interplanetary flight will take place in a coordinate system which is qualitatively different from the system to which man, living on the earth, is accustomed, he will be required to develop in himself new psychic representations corresponding to this system.

In many cases this transition presents serious difficulties, /120
as indicated both by the history of the development of concepts and theories of space-time relationships and experimental psychological investigations. We shall examine some of these

difficulties.

In analyzing the theoretical problems of spatial perception and representation, F. N. Shemyakin identifies three aspects of this problem. The first relates to the material space surrounding man, which exists objectively and independently of human consciousness. Man perceives and is capable of perceiving only material space, which is made up from sensory representation of magnitudes and figures, distances and directions, and also depth. The psychological and psychophysical mechanisms of the origin of the spatial images and localization in space of things and phenomena have been analyzed in some detail. Here we simply note that Helmholtz and Sechenov have stated that in adult man the facts of spatial vision have the form of representations. In the sensory reflection of space by the brain it is extremely difficult to separate perception and representation from one another. Today it is customary to call this connection or fusion of perceptions and representations in sensory cognition of space the "phenomenal" or "perceptive" space.

The second aspect relates to geometric space which, being a reflection of physical space, is not in itself material. This is an ideal space constructed on the basis of a system of geometric axioms. Objective space is studied in physics and geometry. Material space is called "physical" in the sense that its laws are expressed in physics. The expression "Euclidean" or "non-Euclidean" space has a double meaning: one when we speak of ideal geometric space, and another when we speak of material space. When we speak of material space as "Euclidean" or "non-Euclidean" we have in mind that its laws are expressed either in Euclidean geometry or in non-Euclidean geometries.

The ideal space of Euclidean geometry is isotopic, or uniform, at each point of space, and is also isotropic, i.e., the same in all directions from each point. In this space there are no "distinguished" points or "distinguished" directions. "In this ideal geometric space," writes Shemyakin, "we are free to mentally take any point as the coordinate system origin and shift it to any other point. The situation is different with our perceptions of space: in these perceptions there is of necessity a distinguished point — the place where we are located and from which we perceive our surroundings. In these perceptions there are "distinguished" directions — this is the /121
"up-down" pair imposed by earth gravity. The distinguished point serves as the natural coordinate system origin of our perception of space. We can replace it by another point only by leaving our previous location in space. The distinguished pair of directions forms the basis for the fact that we perceive surrounding space relative to the posture of our body, represented as normal: this is its vertical attitude, perpendicular to the horizontal plane of the earth's surface" (1968, p. 20).

E. Hering and H. Stumpf were the first to point out that in our phenomenon space the three pairs of directions are subjectively distinguished. These are the directions "up" and "down," "forward" and "backward," and "right" and "left." Each of these six directions is sensed as a particular quality of space. Therefore, these authors conclude that phenomenon space is not isotropic but is rather anisotropic. Anisotrop is incompatible with the ideal Euclidean geometric space. However, neither Hering nor Stumpf concluded from the anisotrop of phenomenon space that it has a non-Euclidean structure. They assumed that the structure of phenomenon space is expressed in three mutually perpendicular planes of vision. These three planes — horizontal, frontal, and medial — intersect one another at the level of man's eyes when his body is erect. They form a system of rectangular coordinates and in contrast with the Gaussian coordinates characterize non-Euclidean space and only this space. The three pairs of subjectively distinguished directions mentioned above appear as the axes of this coordinate system. Their qualities are the sensory references and perform the functions of the letters "x," "y," and"z," which denote rectangular coordinate axes.

Thus, Hering and Stumpf stated that phenomenon space corresponds in its structure to the ideal Euclidean geometric space. Being nativists, they ascribed to the retina of the eye the inherent capability to provide the Euclidean and no other structure of phenomenon space. They considered this structure to be natural for the eye.

Their opponents — the geneticists — also accepted the Euclidean structure as natural for phenomenon space, although for different motives. H. Lotze, for example, stated that Euclidean uniform and isotropic space defines completely the inner geometric structure of our perceptions and representations. Only Euclidean geometry space is ideal and non-Euclidean geometries are, in the literal expression of Lotze, "a logical barbarism." In contrast with Lotze, Stumpf conceded non-Euclidean geometries /122
a right to existence but evaluated them as "purely analytic space," having no relationship to phenomenon space.

This view of the correspondence between our phenomenon space and ideal Euclidean space reigned in human psychology up until the creation of Einstein's theory of relativity.

The third aspect which Shemyakin identifies in analyzing the spatial perception problem relates to world space. After the experimental confirmation of Einstein's general theory of relativity, it was proved that the inner geometry of world space is non-Euclidean and that Euclidean space represents an infinitesimal part of non-Euclidean universe space.

After creation of the theory of relativity the proponents of the correctness of the three-dimensional viewpoint did not immediately yield their position. Prominent physicists and mathematicians of the turn of the century (Cassirer, Schilder, and others) stated that our perceptions and representations are adapted only to the world of Euclidean geometry and classical mechanics, as a result of which the concepts of space and time in relativity theory are not representable graphically and are forever doomed to "remain on the tip of the pencil." Einstein in his report, "Geometry and Experiment," defended the graphical representability of these concepts. He finished the report with the statement that "human capability for mental representation should not in any way capitulate to non-Euclidean geometry." He repeatedly emphasized that physical space is three-dimensional and that the expression "four-dimensional continuum" indicates only that a fourth coordinate — time — must be added to three-dimensional space.

The physiologist, A. A. Ukhtomskiy, supported Einstein's theory of relativity. He wrote that "man's experience, his basic integrative images and physiological perceptions can be changed and transformed in accordance with the new concepts of space and time" (1950, p. 195).

We have already said that the interconnection between space and time perception is continuous and merged into a sort of space-time continuum. We shall discuss this in more detail in the next chapter. Here we simply note again that neither the space-time continuum nor the structures corresponding to the requirements of non-Euclidean geometry are foreign in any way to our perceptions and representations.

However, in spite of the fact that the theory of relativity in connection with space flights enters into the experience of modern man, this theory is still difficult for people to understand. Ideas on "empty space" and "space as such" still interfere with understanding the theory of relativity. As an example we cite the statements of two subjects, recorded by Shemyakin in conducting experiments on space concepts. "I'm /123
ready to believe that time will pass slower in a space ship than here on the earth," said the first subject, "but I just can't picture this. Imagine that I mentally pass a section through the universe. All points on this section will be synchronous. This means that my "now" is "now" for the entire universe." In this statement space appears as a stationary world reservoir, just as Isaac Newton considered it to be. The statement of the second subject is associated with the deflection of a light ray by the Sun's gravity field: "There is always an ideal perfect straight line connecting two points, in spite of any gravitational fields." The deflection of a light ray by a gravity field, according to the theory of relativity, is one of the facts which indicate the curvature of world space. The subject states that world space "as such" is Euclidean, and its curvature is representable only as a deviation from an ideal plane.

It follows from all this that the cosmonauts performing interplanetary flights must master completely in their concepts the theory of relativity and must be thoroughly trained in navigation in the far reaches of the universe. They must also be quite confident not only in the correctness of the instrument indications (as pilots are) but also in the validity of the mathematical calculations and, in general, in the validity of the reflection of spatial and temporal relationships of space objects by theoretical (abstract) thought.

COSMONAUT PREPARATION FOR ORIENTATION IN OUTER SPACE

> The pilot need not be a cosmonaut,
> but the cosmonaut must fly!

We have already touched on several problems associated with preparation of man for orientation under space flight conditions. Now it is advisable to dwell on certain questions relating to this problem which we have not examined previously.

In the section devoted to psychic reactions under weightless conditions we found that not every individual is capable of withstanding the action of even short-term weightlessness without the appearance of unusual psychic reactions. The facts indicate that the vestibular apparatus analyzer undergoes /124
in space flight the largest specific changes in both intensity and duration in comparison with the other organs and systems.

The realistic picture of long-range flights involves longer stay of the cosmonauts in weightless conditions; therefore, even today our agenda calls for more careful vestibular selection and preparation of the cosmonaut candidates in this regard.

Considerable attention was at one time devoted to the vestibular selection of pilots, as a result of which an effective technique for selection and training was developed.

The experience and knowledge accumulated by aviation medicine were used in selection of the first cosmonauts. But even Titov's flight in Vostok-2, lasting more than 25 hours, showed that the existing methods for studying the vestibular analyzer function do not satisfy entirely the requirements imposed on crew selection for the latest space flight vehicles. The phenomena of vestibular-vegetative discomfort also showed up in Tereshkova, Feoktistov, and Yegorov, all of whom had shown quite high resistance of the vestibular analyzer to motion sickness under earth-bound test conditions.

This is why the problem of developing methods which will show up latent forms of motion sickness remains an urgent one even today. We (Kolosov, Lebedev, Khlebnikov, Chekirda) have attempted to find additional methods for vestibular selection of the cosmonauts which will to some degree fill the existing gap in this question.

Our first choice was parabolic flights, performed on jet fighter airplanes, reproducing short-term weightlessness of duration up to 45-55 seconds in each "hump," for the following reasons.

Under earth conditions the reaction of the otolithic part of the vestibular apparatus is studied during rocking tests in four-bar Khilov swings. During weightless flights along a parabolic curve there is a difference, since in the swings the gravitational inputs change in a smaller range (± 0.4 g) during ascent and descent of the platform, while during flight along the Kepler parabola the gravity input varies in the range from 4-5 to 0 g, i.e., several times stronger.

During space flight the cosmonaut is subjected to noise, vibration, positive linear and angular accelerations, the Coriolis accelerations which arise when the trunk is tilted and the head is turned, weightlessness, and so on. In flight along a parabolic curve the subject encounters the same factors as in space flight, but in a very short time interval and less markedly.

Weightless parabolic flights are arranged so that the weightless "humps" follow one after the other. In this case /125 load factors of up to 5 g arise both prior to and after the weightless period.

The pulse rate, respiration rate, and other vegetative reactions were recorded during the flight. After the flight the subjects wrote their subjective sensations in their flight report.

Prior to and after the weightless flight the subjects were tested by rotating them in a Barany chair. In this test the stability of the vestibular analyzer was studied with respect to three basic components:

1) somatic (nystagmus duration)
2) vegetative (pulse rate, sweating, skin color)
3) sensory (subjective sensations, counter-rotation illusion).

The investigation was made using subjects who had passed with good marks the occupational vestibular selection test using the conventional technique.

Analysis of the data obtained during the weightless flights showed that the primary changes in the sensory component were observed at the time of positive load factor input and during transition from positive load factors to weightlessness. the sensory reactions were somewhat less marked in the period of stabilized weightlessness and at the moment of return to positive load factors.

The subjective sensations observed in the period of positive load factor input were the usual ones and indicated increase of the body weight. An entirely different pattern was observed when the vestibular apparatus received stimuli which differed from those which are usual for earth conditions. In the period of transition to weightlessness 95% of the subjects experienced illusions of climbing, falling down, flight upside down, on the side, on the back, and so on, while a few of the subjects experienced disruption of spatial orientation with changed perception of the surroundings.

It was characteristic that the largest number of cases of unusual psychic states, accompanied by negatively colored emotional background, occurred in the group of individuals without flight experience (63.6%), while a somewhat lower number occurred in pilots with relatively short assignment to flight operations.

In parabolic flight the vegetative component of the vestibular reaction also underwent unique changes, amounting to the following.

The pulse and respiration rates increased rapidly during positive load factor input, and for individuals with poor tolerance for parabolic flight reached pulse rates of 130-140 beats per minute and respiration rates of 28-30 cycles per minute. At the moment of transition from positive load factors to weightlessness there was a slowing of the pulse and res- /126 piration rates on the background of unusual sensory reactions. Naturally, for the individuals who tolerate the flight well, normalization of the pulse and respiration took place rapidly. However, for the individuals with poor tolerance for weightlessness the normalization was very slow, and frequently the pulse and respiration remained at the end of the weightless regime at a high level in comparison with the background values obtained in the horizontal flight segment.

Our observations showed that the time for pulse and respiration normalization in the stabilized weightless segment is very important for prediction purposes. It was found that for individuals with good tolerance to the conditions of parabolic flight pulse and respiration, normalization occurs by the end of ten seconds, while individuals with average tolerance require 31-45 seconds. For prediction purposes it is also important to know how unstable the pulse and respiration rates were in the weightless state. Marked instability of pulse and respiration indicates a predisposition to motion sickness. No less important in evaluating the vestibular reaction were the discomfort sensations: general weakness, languor, sleepiness, headaches, increased salivation, nausea, paleness of the facial skin, blueness of the lips, and general increased tendency toward sweating.

In our studies of a large number of individuals who had previously passed the vestibular selection tests and training in parabolic flights, vestibular vegetative reactions were noted in one pilot and four subjects from the non-pilot group.

In evaluating the results of the rotational tests prior to and after the flights it was found that in individuals with good tolerance to the parabolic flight factors the counter-rotation illusion and post-rotation nystagmus became shorter by 3-5 seconds after the flights in comparison with the background data. However, in those cases in which vegetative disorders were observed in flight, indicating obvious or latent forms of motion sickness, the counter-rotation illusion and post-rotation nystagmus either did not change or increased by 2-5 seconds in comparison with the basic background (5 individuals).

In the next stage of the study we made a 10-fold rotational test in the Barany chair in the flying-laboratory airplane, both in level flight and under weightless conditions. The rotation in the chair was made twice as fast (10 revolutions in 10 seconds) as on the ground. In the first series of experiments using this technique the rotation was accomplished in the period of stable weightlessness, beginning five seconds after the onset of its action. In the second series of experiments with the same individuals the rotation was initiated in the transition period from transition from a load factor of 2 g. The chair was rotated for 5 seconds under positive load factor conditions and the next five seconds in the state of "pure" weightlessness.

The studies conducted with rotation under conditions of stabilized weightlessness disclosed 18.2% of the subjects with latent form of motion sickness. In these subjects we observed 2-5 seconds longer duration of the counter-rotation illusion and the post-rotation nystagmus in comparison with the data in horizontal flight, paleness or reddening of the facial skin, moderate general perspiration, increased salivation, some deterioration of the general condition, and also illusions of changed body posture with the eyes closed. /127

Vegetative-vestibular discomfort was not noted in the other subjects. For most of the subjects the duration of the counter-rotation illusion and the post-rotation nystagmus was shortened by 4-6 seconds, while for some this shortening did not occur.

In the second series of experiments, with initiation of the rotation in the period when positive load factors were operating, an additional 21.9% of motion sickness symptom-complex cases were found among the subjects who had shown high tolerance for angular accelerations under conditions of stable weightlessness. In these subjects the duration of the counter-rotation illusion became longer in comparison with the duration of the illusion when rotating under stable weightless conditions; we observed definite paleness of the face, blueness of the lips, marked general perspiration, nausea, increased salivation, and feelings of discomfort in the stomach region. Termination of the nystagmus could not be established because of the onset of the positive load factors which followed the weightless regime.

Analysis of the data obtained during the flights showed that for individuals who have good tolerance to parabolic flight the counter-rotation illusion and post-rotational nystagmus shortened by 4-5 seconds in comparison with the values for ground conditions. This confirms our assumption concerning the predictive value of the modified Barany test prior to and after weightless flights.

Using this technique, we were able to predict that a tendency toward motion sickness would develop under weightless conditions in several of the subjects who showed good tolerance to weightless flights.

We believe that the appearance of the motion sickness symptom-complex during rotation of the subjects under weightless conditions is due to the following factors. On the one hand, under weightless conditions there are alterations of the functioning of the otolithic part of the vestibular apparatus as a result of the unusual position of the otoliths (floating state), which leads to increased sensitivity to angular accelerations when rotating the chair. On the other hand, motion sickness may result from the appearance of Coriolis accelerations as a result of chair rotation during airplane flight along the parabolic curve.

In those cases when the rotational test was performed during /128
the period of transition from positive load factors to the weightless condition, there was additional stimulation of the otoliths due to abrupt transition from a "plus" stimulus to a "minus" stimulus.

The advantage of this vestibular test technique is that on the background of the gravity field varying periodically from 5 to 0 g and back all the angular motions lead to rapid cumulation of the Coriolis accelerations and strong vegetative reactions. This technique verifies most clearly the stability of the otolithic part of the vestibular apparatus to "minus" stimulation.

The training sessions used to increase the stability of the vestibular apparatus are subdivided into passive and active. The former include rotation of the cosmonauts on various stands, rocking in swings, and excitation of the vestibular apparatus by electric pulses. Since the vestibular analyzer is connected with the sight organs, inputs to the optical analyzer are made during the training sessions in a special rotating drum on the walls of which black and white stripes are painted. In this training the cosmonaut must balance on a chair with unstable support. The active training sessions are conducted during the physical preparation periods, when the cosmonauts along with strengthening the muscular, cardiovascular, respiratory and other body systems also exercise the vestibular apparatus. Here extensive use is made of rotating while on a treadmill and on the Rhine wheel, trampoline jumping, acrobatics, diving, and so on. During the period of immediate preparation for his space flight Leonov traveled more than 100 km by bicycle, ran more than 250 km, skiied the same distance, performed 103 vestibular apparatus training sessions using the passive methods and 56 using the active methods. There were daily apparatus sessions in the gym and other forms of physical preparation (sports activities and so on).

During preparation for space flights considerable attention is devoted to "shaking up" the conventional system of analyzers and increasing the flexibility of the central nervous system. This adaptation, in addition to the methods listed above, takes place during rotation in the centrifuge, weightless flights, thermal exposure, and so on. "Flexibility" conditioning of the neural processes is also provided by testing the neuro-psychic stability of the cosmonauts under isolation chamber conditions, during which the individual must develop new mechanisms for adapting to the changed situation in absolute silence.

All this increases the "flexibility" of the neural system and creates the basis for rapid formation of new functional systems when man enters unusual conditions of existence.

All the cosmonaut training techniques which we have listed briefly have now been quite thoroughly reported in the literature and summarized in the work of N. N. Gurovskiy. Therefore we consider it advisable to dwell in more detail on the importance of cosmonaut flights in airplanes for training with regard to control and orientation in outer space, since there have been only a few individual reports on this aspect. /129

This form of preparation is mandatory for all the cosmonauts, whether they are professional pilots or research personnel. However, in contrast with the flight engineers and scientists, the spacecraft commander must control the airplane himself during flight for training purposes.

During preparation for flight the cosmonauts accustom themselves to the effects of accelerations in the centrifuge, to weightlessness during flights of flying-laboratory airplanes, and so on. These inputs may be separated from one another by long time intervals. In space flight, however, the inputs listed above act on the cosmonaut's organism both one after the other at short intervals of time and also simultaneously. This is why the question has arisen of selecting that form of training session in which these factors will approach those conditions which the cosmonaut encounters in actual space flight. Titov had the following answer to the question of what form of training session is most important for preparing for flight: "Flights in modern supersonic airplanes. They not only develop strength and reaction, like sports and calisthentics, but also develop the professional skills. Each flight is an integrated training session."

Titov himself often flies modern airplane types. In 1967 he was classified as a senior military pilot and became a test pilot. The following is the description of O. Nazarov, a correspondent of the journal, "Aviatsiya i Kosmonavtika," of his sensations during a flight in a two-place fighter piloted by Titov.

"The airplane surged forward with tremendous acceleration and lifted off the strip with a sort of high-pitched roar. A thump as the gear comes up and the body is forced heavily into the seat, the sky rushes in from all sides. We are climbing. Our heading is toward the aerobatic practice area.

"A vertical loop, chandelle, wing roll, another loop... The clouds and sky spin around and I lose all feeling of up and down. The load factor forces you into the seat, only to be replaced by weightlessness. The face mask makes it quite warm.

"Titov heads the fighter straight down and then sharply upward. The load factors press on the hands and feet and then on the whole body like an unseen, soft paw. The forces press heavier and heavier; they envelop the entire body, the fingers become wooden and heavy, the instruments are covered by a sort /130
of haze, vision becomes clouded because of the blood draining away.

"The load factor is about six. This means that my body weighs more than half a ton. Amazing!

"The load factor gradually eases off — Titov is transitioning the fighter smoothly into a new aerobatic maneuver. Now he accelerates the airplane, and then flies along a parabolic arc. An indescribable state of winged lightness takes over. The muscles relax, the body would float if not restrained by the belts. I could float in the air without any support.

"Unfortunately, weightlessness does not last long. However, these few seconds are very important training for familiarization with life away from the earth, where weight disappears.

"Through breaks in the clouds I see the earth, and looking at it one immediately senses the speed of flight, the airplane rate of climb, the colossal power of the engine of this amazing machine.

"Our fighter streaks upward into the sky. The altimeter needle completes a revolution. The airplane rolls over and hangs for some time in this unusual attitude. It feels as if the engine has just quit; the pilot has throttled back. A roll around the airplane's longitudinal axis, another roll, a chandelle, and a steep dive. The airplane transitions from one attitude to another and we finally come back to the ground" (1968, pp. 26027).

We see from this report how positive load factors are replaced by weightlessness. The aerobatic maneuvers caused the correspondent to lose his concepts of "up" and "down." However, the cosmonaut in the role of airplane pilot does not simply condition his organism to load factors, weightlessness, vestibular stimulations, and so on. These are not really the main point. The main point is that he is conditioning himself to control the flight vehicle in space and in time.

The individual flying a jet airplane must have extreme composure, self-control, will-power, and the ability to evaluate the situation literally in a fraction of a second, make a decision, and react instantaneously in accordance with this decision.

In order to get a better understanding of the importance of airplane flights in the cosmonaut preparation system, and specifically in space orientation, we shall analyze what there is in common between flights in airplanes and spacecraft and what the differences are.

In controlling the spacecraft and its systems the cosmonaut uses instrument indications. During the training exercises on the spacecraft simulator the cosmonaut does not become excited while performing these operations, since he knows that there is no danger threatening him.

From the history of World War II we know that some operators worked without error in quiet surroundings with electronic instruments while performing several operations /131
simultaneously. However, under the threat of attack, when emotional stress developed, they forgot to perform important calculations, made errors in the calculations, and lost their ability to calmly evaluate what was going on.

Gurevich and Matveyev present several cases in which operators of large electric power stations lost their capability to perform sensible actions under emergency conditions.

Thus, at one of the large hydroelectric stations the duty operator hurriedly left the control station as soon as signals indicating a serious emergency began to flash on the control panel. Half an hour passed, the emergency was resolved by the efforts of other station personnel, and then the duty operator returned. He explained his absence by the fact that he spent this time in the toilet, which he could not leave for obvious reasons.

At another hydroelectric station the duty operator, after receiving a signal indicating the beginning of a major emergency — failure of power to the most vital city services — plumped down in his chair and just sat there without moving, not responding to telephone rings, paying no attention to what was going on, giving no instructions. The emergency was cleared up by intervention of other personnel. The duty operator left the control panel room in this same state of silence and climbed down the station ladder, never to climb up that ladder again.

These authors report that the workers mentioned here enjoyed well-deserved reputations in their plants and were considered well-qualified specialists who handled their duties conscientiously. Their behavior during the emergency can apparently be explained only by the influence of the emergency situation, which caused an inadequate reaction, disorganized their thinking and entire behavior.

In the next chapter we shall discuss in detail the development of emotional and volitional qualities in the cosmonauts. Here we simply note that the control of an airplane always takes place on a definite emotional background, since there is always a real danger of catastrophe in the case of improper actions of the pilot, failures of the hardware, and also in other unforeseen situations. An example of such a situation is an episode from the flight experience of Titov which took place in 1967.

While flying at an altitude above 25 km in a fighter, unexpectedly the engine shut down. There was a solid overcast covering the ground from 1500 to 10,000 meters. The fighter descended 16 km with the engine dead. Titov did not lose his head. Making one attempt after another, he finally restarted /132 the engine and terminated the flight without any problem.

We have mentioned previously that automatic equipment has failed in spacecraft during flight. Thus, during the landing of Voskhod-2, in which one of the authors flew, it happened that one of the commands for activation of the automatic orientation system did not go through. The crew was instructed to land the ship using the manual mode. Belyayev analyzed the situation, oriented the ship, and activated the retro powerplant precisely at the calculated time. In performing the maneuver he performed calmly and confidently. His extensive professional experience paid off. Being a fighter pilot, he had operated under unexpected and emergency conditions many times.

An unexpected condition arose in docking the lunar module with the command module during the Apollo-10 flight.

After two approaches to the moon, the astronauts fired the engines to maneuver in orbit in order to ensure rendezvous and docking with the spacecraft. When the astronauts separated the landing stage of the lunar module from the ascent stage, in which the cockpit was located, the ascent stage suddenly began to rotate at high speed around the longitudinal axis. It even seemed to astronaut Cernan that they would fall back on the moon. At this critical moment astronaut Stafford took control and stabilized the ascent stage. The reason for the rotation was incorrect positioning of a switch in the automatic orientation system. The maneuvering of the lunar module was completed with successful docking with the command ship.

We have already mentioned that with the development of space technology there is an increase in the number of instruments appearing on the manned spacecraft instrument panels.

The cosmonaut can develop during airplane flights skills in rapid and precise reading of the instrument indications and evaluating on the basis of these readings the status and operation of the systems and also the attitude of the flight vehicle in space. These flights are also a good school for acquiring skills in overcoming the spatial illusions which arise in orienting the space vehicle solely by instrument indications.

Airplane flights also aid in the development of such psychological qualities as attentiveness and vigilance, which are necessary for the cosmonaut throughout the flight and particularly during landing on the earth, moon, and other planets; ability to react adequately to situational changes under conditions of limited time or even time deficit, and so on.

Airplane flights are of assistance in all-round preparation of the cosmonauts for situations in which they are subjected to both physical and psychological factors. During flight the pilot must control the flight vehicle actively, know the /133 theory and hardware, and act quickly but at the same time judiciously.

There are, naturally, significant differences in the control of an airplane and a spacecraft. For example, airplane control is based on aerodynamic laws while spacecraft control is based on inertial laws. However, the phenomenon of skill generalization and transfer is well-known from work psychology. By virtue of this the tractor driver acquires tank driving skills faster than, say, a teacher; the chauffeur who drives several cars rapidly masters one with which he is not familiar; the test pilot who is familiar with various types of airplanes handles a new model comparatively easily; and the individual who knows several languages masters still another without much difficulty.

As a result of the possibility of skill transfer, the cosmonauts utilize in controlling the spacecraft many of the skills which they acquire during airplane flights. This is why airplane flights are the quintessence of cosmonaut preparation.

CHAPTER 3

PERCEPTION OF TIME IN OUTER SPACE /134

In performing the tasks assigned him, carrying out extremely varied work operations, and so on, the cosmonaut must plan his actions precisely in time. This is particularly important in spacecraft control, since here both slowly varying processes and control operations with a rigid time limit or even time deficit are encountered (the emergency situation case and so on). We shall clarify these remarks by some examples. Thus, in orienting the spacecraft on some celestial body the cosmonaut acts through the control stick to send an impulse to one of the reaction engines. After this the spacecraft begins to rotate about its center of mass in pitch or with respect to the other axes. Prior to completion of the rotation through the required angle, the cosmonaut switches off the operating engine and activates another engine to give an impulse for rotation in the opposite direction. In spite of this the vehicle continues its initial rotation by inertia. Only after some time does the vehicle come to a stop. In order that the stop take place at a given point the cosmonaut must determine precisely the moment for activating the second engine (and subsequent shutdown). Otherwise the attitude change will require excessive time and will be accomplished by means of numerous trials and errors and with considerable expenditure of propellant. In the case cited the time is not rigidly limited; however, even more complex situations may be encountered in space flight. Thus, in accomplishing a lunar landing using the manual system the American astronauts were forced to expend no more than 75 seconds on this operation. During this time it was necessary to select the landing area, orient the lunar module vertically (descent stage along the direction to the lunar surface), gradually reduce the rocket engine thrust, and shut the engine down just above the lunar surface itself.

Precise time perception can be developed (and this is constantly done) under conventional terrestrial conditions. However, in space flight the human organism is subjected to weightlessness, "sensory deprivation," large load factors, and so on. High emotional stress results from the unusual and extreme influences on the cosmonauts. All this in one way or another prevents (or may prevent) adequate reflection of both space and time relations. This then leads to the problem of studying the effect of various space flight factors on the perception of time, and also the problem of finding the ways, techniques, and means which are necessary to ensure proper perception of time by man under the conditions of space flight. /135

PSYCHOPHYSIOLOGICAL MECHANISMS OF TIME PERCEPTION

> Life without regard for time is just as great an absurdity as life without regard for space.
>
> F. Engels

In his book Materialism and Empiriocriticism, Lenin presents the views of the English Machist Pearson, who stated: "Like space, time is one of the plans) by which this magnificent sorting machine, human cognition, arranges its material."[1] According to the viewpoint of Pearson, time is not infinite, is not infinitely divisible, but is essentially limited by the content of our representations.

In criticizing these concepts of the idealist philosophers, Lenin cites Engels and indicates that man's concepts of space and time are relative, "but from these relative concepts there is formed absolute truth, these relative ideas as they develop travel along the line of absolute truth and approach the latter."[2]

According to the modern concepts, man has no separate temporal analyzer. Sechenov was the first to point out that the perception of time, just as the perception of space, is accomplished by several "sensitive instruments." At the present time the concept that man (in contrast with the animals) has two different but mutually complementary systems for the perception of time is widely held in psychology and physiology of the higher nervous activity. One of these sensing systems is based on the /136 first signal system while the other, more complex and advanced form of time reflection is accomplished by the second signal system. Let us examine the inter-relationship of these two systems in human reflection of time.

In 1912 Yu. P. Feokritov, working in Pavlov's laboratory, found that if a dog is fed every 30 minutes he develops conditioned reflex salivation at these time intervals. In the experiments of F. L. Ruch rats developed the capability of reacting sufficiently slowly to avoid walking through a grid through which an electric current was passed for some time and sufficiently

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(1) Lenin, V. I. Complete Collected Works, Vol. 18, p. 190.

(2) Lenin, V. I. Complete Collected Works, Vol. 18, p. 181.

quickly so as not to remain outside a door which closes after some time interval.

In analyzing the physiological mechanism of the conditioned reflex to time, Pavlov wrote: "How are we to understand physiologically time as a conditioned stimulus? Naturally a precise and definite answer to this question cannot yet be given. But we can approach a certain understanding of this problem. How do we note time in general? We do this with the aid of various cyclic phenomena: rising and setting of the Sun, movement of hands over the clock face, and so on. But there are also several of these cyclic phenomena in our bodies. During the day the brain is stimulated, tires, and then recovers. The alimentary canal is periodically occupied by food and is then cleared of food, and so on. And since every state of the organ can be reflected on the large hemispheres, this is also a basis on which to differentiate one moment of time from another. Take short time intervals. When a stimulus has just been applied, it is sensed very sharply. When we enter a room with an odor, we initially sense it very strongly and then less and less. Under the influence of stimulation the state of the nerve cell experiences several changes. And the same occurs in the reverse direction. When the stimulus terminates, it is initially still sensed very strongly, then more and more faintly, and finally we do not notice it at all. This means that, once again, there is a series of different states of the nervous system. From this viewpoint we can understand both the case of reflexes to interruption stimulus and trace reflexes, and also the case of time reflex. In the cited experiment the animal was periodically fed and in this connection several organs showed definite activity, i.e., they experienced a series of definite sequential changes. All this affected the large hemispheres, was processed by them and the time of these changes was made definite by the conditioned stimulus" (1951-1952, p. 57).

Thus, cyclic phenomena in the different organs of an animal can serve essentially as biological clocks, which permit the animal to "measure off" particular time intervals. This is also confirmed by the fact that the isolated organs and tissues actually do retain under certain conditions an autonomous activity rhythm (for example, an extracted heart continues rhythmic contraction with a definite frequency, and so on, which will be discussed in greater detail later on). /137

In man the evaluation of time can also take place at other levels, by conscious use of definite reference points; however, we should not underestimate on this basis the cyclic phenomena in our organism for the perception of time.

In the course of his study of the time concept formulation process, Sechenov came to the conclusion that any of the sense organs is capable of perceiving time intervals. In other words, time concepts can arise on the basis of auditory, visual, tactile, and other sensations. Sechenov gave particularly great importance in this aspect to the musculo-articular sensations. Among the acts yielding muscular sensations Sechenov noted particularly walking. He believed that "in the various sense aspects of the walking act, this most common of phenomena, there are included for man elements not only for constructing numbers in all their definiteness but also for measuring lengths and short time segments" (1952, p. 188). The step serves as the basic unit of periodic motion performed during walking. The step is used as both a space measure and a time measure. Since the step is sounded out it is sensed not only by the muscles, but also by the ear. This gives rise to simultaneity, the association of two sensations, each of which reinforces the other and yields a clear perception of the time interval. More than that, according to Sechenov, hearing together with muscle sensations is prepared to the greatest degree for analysis of rate and rhythm, since the very arrangement of the hearing apparatus and its inherent functions make it more adapted to differentiation between preceding and succeeding events. S. G. Gellershetyn shows that numerous facts relating to the perception of speech and music with characteristic tempo peculiarities — pauses, lines, and so on, confirm this idea.

Of particular interest is the role of the walking act in the perception of short pauses. Sechenov considered that the capability of sensing their duration "cannot be learned exclusively in the school of hearing." During the time of a pause the hearing apparatus is inactive. Therefore, he connected the capability of estimating short time periods with the basic periodic movements of the body, primarily in the act of walking. According to Sechenov, walking at different rates appears to the consciousness as a periodic series of short sounds, the pauses between which are filled by muscular sensation. He called walking a "school", in which the ear could learn to estimate the different duration of the interval in the case of speed-up or slowdown of the steps.

In general, the act of walking consists of both "periodic measuring off of steps" in space and a "sound series with constant duration of empty intervals." The muscular sense accompanying the step becomes a "measure or fractional analyzer of space and time". However, while perception of the latter by means of kinesthetic (muscular-articular) sensitivity is least differentiated, in the other analyzers such differentiation is present in adequate measure. /138

For example, the visual receptor is the best organ for spatial perception. At the same time it plays a definite role in the perception of time, since the operation of the eye also involves movements (accommodation and convergence). Sechenov likened the visual axes of the eyes as they track something to two long feelers, which are capable of either extension or contraction as a function of whether or not the observed object moving in space is receding or approaching. These feelers essentially reproduce the entire path of the object and the rate of its movement. This is why the muscular sensations which arise during operation of the visual receptors make it possible to evaluate not only the spatial but also the temporal characteristics of the object. This has been specifically demonstrated in special studies of El'kin and his students. It is true that time is sensed by the visual analyzer much poorer than is space. "This is seen from the fact," writes El'kin, "that the error in space perception in the visual sensing process is considerably smaller than the error in duration estimation" (1962, p. 126).

The situation is different with the hearing organ. It serves (in addition to sensing sound) for the perception primarily of time intervals, although as mentioned above it may also facilitate the perception of space relationships. We see from El'kin's work that the perception of the temporal characteristics of sound stimuli — duration, frequency, rhythm — involves a unique motor accompaniment, in which the trunk, head, extremities (particularly the upper), and the vocal apparatus participate. This motor accompaniment, tuning itself in unison with the stimulus as a feedback, simulates the latter to a definite degree and thus ensures adequacy of the reflecting ability. The correlated motor activity in the time perception process is the equivalent of the "feelers" discussed by Sechenov in application to the perception of space with the aid of the sight organs. It is no accident that the perception of rhythm loses much of its precision when there is damage to the motor sphere.

The tactile and interoceptive analyzers also participate in the perception of time. However, as A. R. Luriya emphasizes, in general this perception is accomplished with the aid of several analyzers which combine into a sort of system which acts /139 as an integrated whole. Different dynamic "composition" of the higher nervous activity corresponds to different nature of the temporal sensations.

From experiments conducted in Pavlov's laboratory, it is known that animals can orient themselves in time to within a second. But this cannot be compared in any way with the orientation of man, who is capable of abstract thinking accomplished on the basis of the second signal system. Sechenov wrote that we sense the duration of short-lived phenomena because we differentiate their beginning, middle, and end. But there is no man in the world who can differentiate directly by his senses the degree of duration of phenomena beyond the limits of seconds; yet we think not only in minutes but even in years and centuries — and, naturally, again in terms foreign to our senses (1952, p. 403). Sechenov's idea is in agreement with that of Lenin, who wrote the following in a review of Hegel's "Science of Logic": "Is representation closer to reality than thought? Yes and no. Representation cannot embrace motion as a whole, for example, it cannot embrace a motion with a speed of 300,000 km/sec, while <u>thought</u> can and must embrace such speeds. Thought, taken from representation, also reflects reality; time is a form of existence of objective reality."(3) It is interesting to observe how children who are just beginning to speak begin to adapt to the perception of time. While prior to the development of speech only limited rhythmicity (feeding at established hours,

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(3)V. I. Lenin, Complete Collected Works, Vol. 29, p. 209.

sleeping, and so on) and the conditioned reflexes which are formed on the basis of this rhythmicity make possible some preparation of the organism for what is coming, when speech is mastered these capabilities begin to broaden. Let us take a simple example from the observations of Decroli and Degan, when a two-year-old child says (in his own way): "I drank my milk, I'm going outside." In this phrase he expresses the sequence which he has experienced and places himself at a known position in relation to this sequence. On the basis of the present situation he both recalls the past and pictures the future moments of this sequence. At first glance there is nothing new here: the child translates into his speech pattern what he already knows how to do. "However, in reality," writes P. Fress, "in this translation there is a complete revolution; mastering the law of succession. Before the child there opens up a temporal perspective with past and future polarity. As his speech develops, the capabilities for reconstructing the past and foreseeing the future expand. The adequate use by the child of terms denoting periods of time more and more remote from the present is an indication of this broadening of his temporal perspective: he begins to differentiate morning from evening, yes- /140
terday from today, the day from the week, month, year, and so on."

At about the age of seven or eight the child learns to tell time. However, at this age he does not yet perceive time as something independent of human activities. Sometimes he thinks he can alter time by shifting the hands of the clock. Only in the early teens, when he becomes capable of abstract representation, does he come to the conclusion that time is independent of such operations. In this period the child includes himself in the history of his family, country, and finally, all mankind. His plans begin to extend to distant perspectives which have not yet been encountered in his own experience. For example, he can now dream about his future profession or the achievement of other distant goals.

Human abstract thinking appeared as a result of the initiation and growth of social production, joint transformational activity of people in relation to nature. In the same way, the perception of time by man, just as all his psychic activity, takes shape and is formed under the conditions of work activity, social and productive practice as a whole. S. L. Rubinshteyn indicates that it would not be correct to think that people simply expose themselves in their activities, remaining after these activities the same as they were previously. To the degree that man, realizing himself objectively, personifies himself in the products of his labor, he himself changes and develops. And El'kin writes quite correctly: "If we trace the development of man's orientation in time in the course of the social and historical process, it becomes obvious that this orientation has been shaped and formed inseparably with work activity. Essentially, the entire path of the historical development of man's orientation in time is the long path of development of man's work activity, his practical work" (1962, p. 212).

We can establish some unique characteristics of man's orientation in time as a function of various historical conditions and levels in the progress of society. Thus, Lebbon wrote that primitive man lived primarily in the present; for him the past was short and unclear. This is explained by the very low level of development of productive forces at that time. The working process, very primitive in its nature, was limited in privitive man to narrow temporal limits; as a rule the working process all took place in the present, not requiring the advancement of goals into the future, not continuing what has been started in the past. As a result of the rudimentary level of working activity its stages were in general weakly differentiated. This led to completely inadequate differentiation of the past, present, and future.

With the progress in productive forces, man faced the practical necessity of evaluating the duration of considerable inter- /141 vals of time, of studying events of the distant past, of predicting the future (flooding of rivers, favorable times for initiation of sowing, and so on). Various auxiliary techniques and means began to be created to perform problems of this sort. For example, the so-called time reference points were introduced. On the other hand, even Aristotle knew that "measurement of time is achieved by measurement of motions and motion is determined by time." The time measurement instruments capable today of precision to millionths of a second or less have traveled a very long historical path. But even today various motions which have the same duration and periodicity serve mankind as a measure of time.

Time perception, being associated with definite psychophysiological mechanisms and their systems, can be disrupted, particularly in the case of damage to the brain centers. We shall present some characteristic examples.

Patient S is 32 years old and damage to the thalamus has been diagnosed, evidenced in the form of thalamic symptoms. The patient's perception of time is seen to be disrupted: she estimates short time intervals incorrectly. The doctor asks S to tell when one minute has passed from a starting time he announces. After 5 - 7 seconds the patient says a minute has passed. She also takes an interval of 5 - 10 seconds marked off for her to be a minute. During the first weeks the patient was disoriented in the present, could not name the current year, month, or date, could not define the duration of her stay in the hospital, and took morning to be evening.

In other cases individuals are not capable of planning their actions in time when there is damage to the frontal lobes of the brain hemispheric cortex. As an illustration, we present an observation of Penfield.

After resection of part of the right frontal lobe in connection with a brain tumor, the patient did not show any major disruptions of behavior or intellect. Disturbance of her time orientation was discovered quite by accident. She decided to arrange a dinner to celebrate her recovery and invited guests. She was busy with the preparations from early morning; however, when the guests gathered it was found that nothing was ready. The patient was not capable of planning her actions in time.

In all probability this disturption is associated with damage to the frontal lobes of the brain hemispheric cortex. As is well known, in man the frontal lobes are intimately connected with the intellect and capability for planning one's actions.

Thus, clinical data also indicate that systematic activity of the different brain segments rather than the functioning of some special "center" forms the basis of time perception. Since this systematic activity has been formulated as a result of the long evolutional and historical development of man under terres- /142
trial conditions, a question arises, which was posed in the preceding chapter and discussed in relation to the perception of space: can man reflect time adequately under the unusual conditions of outer space? We shall turn to an examination of this question.

INFLUENCE OF EMOTIONS ON REFLECTION OF TIME RELATIONSHIPS

> Of all things we have the least of time and need the most of it.
>
> G. Buffon

During their flights, the cosmonauts experience various emotional states. These include the natural desire to explore the unknown, the sense of duty and responsibility for completing the mission, excitement, and fear. These experiences have a dynamic nature, now following after one another in sequence, now appearing simultaneously in contradictory form.

In January of 1968 a successful manual docking of the Soyuz-4 and Soyuz-5 spacecraft was accomplished under the piloting of Shatalov and Volynov, and the other two cosmonauts, Yeliseyev and Khrunov, transferred from one ship to the other.

This maneuver is to some degree like aerial refueling of an airplane. The refueling operation requires tremendous attention on the part of the pilot, a high degree of precision, and exceptional motor coordination. The studies of F. P. Kosmolinskiy and coauthors showed that in such situations the pilots are under great emotional stress, accompanied by marked physiological shifts. The heart beat reaches extreme limits (up to 160 - 186 per minute), exceeding the norm by 2 - 3 times. The breathing rate increases correspondingly to 40 - 54 per minute (2.5 - 3 times the usual value). The moisture losses increase sharply, reaching 5 - 7% of the pilot's weight. The body temperature increases by 0.7 - 1.2°. Large biochemical changes in the blood composition are noted.

After making a psychophysiological analysis of these phenomena, Gorbov, Kosmolinskiy, and Myasnikov came to the conclusion that this marked nervous and emotional stress of the pilot of a refueling airplane depends on several factors. One important factor is the stress which develops in the pilot as a result of narrowing of his spatial field: because of the closeness of the tanker airplane, the unlimited reaches of the air ocean suddenly become amazingly "tight". Moreover, the airplane coupling operation causes definite psychological difficulty involved with the combination of two forms of activity: the usual piloting of the airplane on the basis of the previously ingrained, firmly developed, automatized skills, and the necessity for performing the additional, relatively new, and less familiar to the pilot refueling task. "The considerable dominance of the psychic emphasis on the performance of this new, and therefore not ingrained into a stereotype, activity is the dominant factor which essentially suppresses the ingrained piloting habits and thereby leads to a difficult neuropsychic state" (1966, p. 69). /143

Tremendous emotional load is imposed on the cosmonaut in emergency situations, for example when because of failure of the automatic system he must land the spacecraft using the manual mode. Only a very slight error in orientation and the spacecraft will shift into another orbit, from which it cannot be returned to earth. Even in the case of proper but somewhat delayed orientation it is not impossible that the spacecraft may touch down in unfavorable regions (mountains, taiga, ocean, desert).

Man's subjective perception of time may change in emergency conditions under the influence of emotions. The following episode is from the book "Tested in the Sky", by M. L. Gallay, honored test pilot of the USSR. "During a test of the Lavochkin-5 airplane the engine began to 'race'.

"Worse yet, a long tongue of flame burst out from under the cowling and licked voraciously around the cockpit canopy. Acrid blue smoke poured into the cockpit from below, from under the rudder pedals.

"One thing on top of another — fire in the air. One of the worst things that can happen aboard a small island made of wood and metal, dangling somewhere between sky and earth, and carrying in its tanks hundreds of liters of gasoline.

"The typical full-fledged aerial 'circus' developed. As always in critical situations, I gave a start and began to act in accordance with some strange 'double' time scale. Each second took on the capability of expanding without limit — as much as was needed; man can do so very many things in such situations. It seems as if the passage of time has nearly stopped. But not really, here is one effect of the 'double' scale: in such situations man does not sense any unfilled gaps or leisurely pauses. Rather, time itself urges man on! Time not only does not stop, it runs faster than usual. If only man could always make use of time skillfully, without having either too much or too little of it.

"Nearly automatic movements — they required much less time /144
than it takes to tell what happened; I throttled back, turned off the ignition, closed the fuel line fire shutoff valve, moved the governor lever to minimum rpm, and made a steep turn toward the field."

We shall cite another case from flight experience which involved a change of time perception in an emergency situation, described by B. S. Alyakrinskiy.

During cruising flight the airplane caught fire. There were two other crew members in addition to the pilot. The pilot ejected while the other crew members were killed, although they also had ejection seats. In studying the accident, it was found that the pilot (commander of the ship) gave a signal to bail out prior to his ejection; however, according to his statement, he did not receive any answer although he waited several minutes. Actually, however, the time interval between the moment of the command and the moment of ejection was only a few seconds. The remaining crew members were not able to prepare for ejection during this time interval, since preparation required the performance of several operations in this particular airplane. The overestimation of the long time interval in this case is quite obvious. Fractions of a second were perceived subjectively as minutes, and this led to the death of the other two crew members.

Since the cosmonaut must evaluate time intervals precisely and operate the spacecraft controls in accordance with this evaluation, we need to examine in more detail the psychophysiological nature of the subjective perception of time passage in connection with different emotional states.

Precise experimental studies have now established that an individual experiencing positive emotions underestimates time intervals, i.e., for this individual the subjective passage of time is quickened; however, in the case of negative emotional experiences the time intervals are overestimated, i.e., a subjective slowing of passage time is observed.

In this regard, the experiments conducted by M. F. Ponomarev are of interest. He made a study of the range at which aerial firing against ground targets was initiated by the students of one of the aviation schools. He found that 44% of the students initiated firing prematurely. Ponomarev believes that premature opening of fire is associated with excessive "over-insurance", with the fear of "not succeeding" in performing the mission (particularly during the first flights when firing against a rapidly moving target).

The physiological basis for this psychic process is domination of the inhibitory process in the brain hemisphere cortex over the excitatory process. Ponomarev confirmed this conclusion by special studies. The subjects were to stop the sweep hand of a stopwatch on a definite division (reaction to a moving object or abbreviated as RMO). After practice sessions, the subjects in one series of experiments were given a bromide by the tester to intensify the inhibitory process, while in another series of tests they were given caffein to intensify the excitatory process. It was found that in the first case premature reactions to the moving target were dominant for the subjects, while in the second case lagging reactions dominated. Thus, prematurity, i.e., overestimation of time segments, in the case of an emotional stress accompanied by a feeling of fear or fright, has as its cause disruption of nerve process balance in favor of inhibition. This thesis corresponds to the view of Pavlov, who wrote: "What is termed psychologically fear, cowardice, timidity has as its physiological substrate an inhibitory state of the large hemispheres and represents different degrees of the passive-defense reflex" (1951 - 1952, Vol. 4, p. 432). /145

Clinical observations of patients with manic-depressive psychosis indicate the same thing. Time seems to pass extremely fast for such patients while in the manic state, when the excitatory process dominates. "I hardly get up before I again lie down," complained one female patient. "As soon as I sit down at the table I think that this is the end of the meal and I must get up. I am sometimes amazed to find that I have eaten in two or three minutes. I often refuse to believe it when they tell me that several hours have passed. How is it possible that time can pass so fast? Why is this so? Why does it not pass the way it appears to me?" The reverse picture is observed in the depressive state, when the inhibitory processes dominate. One patient had the following to say after a depression period which had lasted about three months: "It was as if everything were dead. The whole world had died. Very depressing. People moved extremely slowly. Everything floats away somewhere. Time has stopped. Time has passed and frozen. I have died or never will die. I know that the hand is moving on my watch, but this is only an illusion of motion... You are coming to me from out of another time."

Ponomarev emphasizes that the fact that excitation causes delayed actions and inhibition causes premature reactions is paradoxical and contradicts common sense. However, this situation can be understood if we consider the nature of the basic nerve processes. In contrast with excitation, inhibition always shows up in shortening, limiting, reduction of activity. Moreover, from the psychological viewpoint it is possible that a definite (excited or inhibited) state of the brain cortex leads /146 to a corresponding perception of reality and the latter, in turn, leads to a tendency toward either delayed or premature reaction.

Thus, the connection between premature reaction and inhibition, caused by the most varied agents, including negative emotions, and between delaying reaction and excitation (also caused by various factors) is accomplished through subjective slowdown or speedup of the passage of time in the consciousness. If some time interval seems, say, shorter than it actually is, then in the reproduction of this interval in the consciousness a longer time interval is actually created. Such a relationship between time perception (and therefore time reproduction) and subsequent actions is clearly observed in the case of parachuting with delayed chute opening.

Parachutists are first trained in reproducing 5 and 10 second and so on intervals under ordinary conditions on the ground. To facilitate the performance of this task, the parachutists usually count the time interval mentally. Then they reproduce this count during the free fall and open the parachute accordingly.

From the psychological viewpoint three stages can be identified in the delayed-jump free-fall process: the reference point, coinciding with the moment of separation from the flight vehicle; the count itself, which coincides with the free-fall; and the count endpoint, corresponding with pulling the parachute ring. These two points represent moments of time which are fixed by the individual. As for the count itself, it is simply a reproduction of a given time interval. Here certain difficulties arise for the beginning parachutists because of their negative emotions. The recollections of a parachuting veteran P. P. Polosukhin describe these difficulties well: "A friend of mine who had made more than a hundred jumps from airplanes and balloons was for some reason afraid to 'delay'. Several times he tried to delay opening the chute for at least 10 seconds, but he always pulled the ring the instant he started falling. Several times he decided to take himself in hand and began to train carefully to develop uniform counting of seconds on the ground. He walked around all day long muttering to himself: 'One....two....three....four.' But in the air everything went as before. When he jumped from the balloon I was still in the gondola and heard a sort of unintelligible exclamation, indicating the count, and immediately saw the chute open" (1958, p. 142).

Numerous observations made in the course of preparation of sport parachutists and airborne troops permit us to conclude that during parachute jumps not only are the skills in separating /147 from the airplane, parachuting itself, and landing developed, but it is also very important that such qualities of the will as purposefulness, coolness, self-control, decisiveness, and bravery are developed as well.

This is why, in addition to developing professional skills, the parachute training of the cosmonauts was directed basically toward the development of the will qualities and reproduction of time intervals in this highly emotional situation.

During the ground training period the cosmonauts developed skill in reproducing 10-, 15-, 20-, 30-, and 50-second intervals. The reproduction skill was considered developed if the error did not exceed ± 0.5 seconds.

In the course of the parachute training, constant psychological observation of the cosmonauts was maintained (speech, gestures, facial expression, motor skill development). Movies were taken to record the emotional states. The cosmonauts were given a thorough medical examination one to two hours before jumping, with electrocardiogram recordings and various tests being made. Similar tests were made after the parachute jumps.

The cosmonaut's pulse rate was determined, and wrist dynamometry recordings were made prior to boarding the airplane, while in the airplane, and after landing.

According to the observations of Aleksandrov, Lebedinskiy, and others, and also our own observations, in many individuals who are jumping for the first time the very prospect of the jump causes change of their normal state and mood. Inadequate confidence in reliable operation of the chute and the absence of safeguards make a definite imprint on the emotional state of the individual. On the evening before the day when the jump is planned many individuals are restless, doubtful and fearful, and their sleep becomes uneasy. At this moment we can observe increase of the arterial blood pressure, quickening of the pulse and respiration, sometimes increased perspiration and other vegetative reactions.

All the observers noted increase of the pulse rate in the first-time jumpers, in some cases to 120 - 140 or more per minute when boarding the airplane and during the flight; marked paleness, dryness of the mouth, widening pupils were also observed. Their behavior also changed. Some became torpid, had the shakes, or became withdrawn and restrained. In certain cases the tension was so strongly marked that it was reminiscent of the stuporous state with phenomena of psychic depression and indifference to the surroundings. The described state is a manifestation of the asthenic fear reaction, taking place through the mechanism of the passive-defense reflex. Some tension was observed among the cosmonauts prior to their first jumps. Along with this there was difficulty in developing skill /148 in controlling the body during the free fall. The tension began to disappear beginning with the seventh jump. In the subsequent jumps they controlled themselves quite well and completed the training successfully. In other first-time jumpers we noted motor excitation, talkativeness, wandering of the attention, and difficulty in concentrating. For example, excessive liveliness and paleness of the facial skin was noted prior to the first jumps of V. F. Bykovskiy. He mastered the free fall skills by the ninth jump, after which he had good control of himself prior to boarding the airplane.

Judging by my own experience and the statement of most parachutists, the moment of separation from the airplane during the first jump is the most difficult and most memorable experience. The tension reaches its highest level when the commands "ready" and "out" are given. It is at this moment of separation from the airplane that active willpower is necessary to overcome the emotion of fear. In certain cases inability to develop this willpower leads to refusal to jump at the very last moment.

After separation from the airplane the jumper is subjected for several seconds prior to chute opening to a series of brief but marked and unusual inputs (state of reduced weight, airstream, change of barometric pressure, and so on), which cause several new sensations. Several authors (Arskiy, Gordon, Gorovoy-Shaltan, and others) have found that disruptions in the mental state are characteristic at this moment for individuals jumping for the first time, and they are not able to recognize and then reproduce in their memory the details and sensations which they experience in the first few seconds of free fall.

We have also noted these disruptions of the mental state in the cosmonauts. Bykovskiy characterized this state as follows: "I do not recall how I pushed away from the airplane. I only began to think when I pulled the cord and the canopy 'burst' above my head." One of the present authors (Lebedev) experienced a similar condition when he made his first parachute jump.

Gorbov was able to clarify the nature of the mental state disruption in such situations and reproduce them experimentally. Most parachutists do not lose awareness in the period of separation from the airplane and in the first seconds of the free fall. This is shown by their continued activity, particularly opening of the chute by pulling the ring. The "blackout" condition is associated with strong emotional tension of the jumper. This shows up not in interruption of activity but in interruption of recall of actions which he has just completed. According to the data of Gorbov, "this makes it possible to relate this form of paroxysm not to the category of disruptions of awareness, but rather to the category of disruptions of the short-term operative memory, i.e., the memory which organizes itself in the course of and in connection with continuous activity" (1963, pp. 15 - 16). /14

After the parachute opens, most jumpers feel a joyful lift of their mood, often transitioning into euphoria. Usually, very little attention is devoted to the elements of the landing at this moment. After landing, the individuals who are jumping for the first time often have no critical impression of what has happened. Most report: "It wasn't frightening at all, I was not afraid at all," and so on. Many express a desire to repeat the jump immediately. More precise data on the experiences during the time of the jump can be obtained the next day, when the euphoria ends and a critical approach to the completed jump becomes possible.

Thus, in the process of a parachute jump being made for the first time, we observe manifestations of strong tension and transition of the emotional states from sensations of fright and fear at the moment of leaving the airplane to the lift in spirits after the parachute opens and also after touchdown occurs.

One of the objective indices of emotional stress is increased muscular activity. Many cases are known in which an individual in a state of anger or great fear demonstrated strength which was very unusual for him (tremendous speed in running, fantastic jumping ability, and so on). Pavlov discovered the reason behind this intimate connection between the emotions and muscular movements and reported that: "If we go back to our distant ancestors we see that in their time everything was based on muscles.... You cannot imagine any wild beast lying in ambush and becoming angry without all sorts of muscular manifestations of his anger. Our ancestors really did not differ much from the wild beasts, and in the same way all of their feelings were transformed into muscular activity. For example, when the lion becomes angry this pours out of him in the form of scuffling, the frightened rabbit immediately starts a different type of activity — running — and so on. And in our zoological ancestors everything showed up in the form directly as some sort of activity of the skeletal musculature: in fear they ran from danger, in anger they threw themselves on their enemy, they protected the life of their child, and so on" (1952, Vol., 5, p. 332).

In the process of historical development man has learned to control his movements at will. The situation is different with the tonus (tension) of the muscles in regard to emotional states. Under the influence of nerve impulses traveling from the central nervous system and as a result of excretion of adrenalin by the internal secretion glands, muscle tonus changes and their potential capability increases markedly. The tonus increase is sometimes accompanied by trembling, which is explained by nonuniformity of the tension of the individual muscle groups. Distinct shifts in the muscle tonus variation were /150
observed in the cosmonauts when making wrist dynamometric

measurements during parachute jumps. The indices of wrist strength prior to boarding the airplane are illustrated by the following values:

	Initial value	1st jump day	20th jump day
Gagarin	52/49*	54/48	46/44
Titov	44/43	50/50	49/47
Nikolayev	56/51	68/56	51/53
Popovich	47/47	50/48	–
Bykovskiy	52/45	56/50	53/50
Leonov	64/60	67/62	62/62
Volynov	60/53	71/65	72/62
Khrunov	47/47	50/50	48/48
Shonin	54/46	53/49	52/48
Gorbatko	55/43	58/50	53/44

*Numerator is value for right wrist, denominator is value for the left wrist.

We see from these values that the strength indices increased in nearly all cases for the cosmonauts on the first jump day. In the succeeding jumps the dynamometry indices approached the initial values. The following fact confirms that the muscular strength increase was caused by emotional stress. Two cosmonauts who had also planned to participate in the jumps were told immediately prior to takeoff that they would not jump that day. The immediate result was a marked decrease of the strength indices.

From the days of antiquity people have associated their emotions with the activity of the heart. It is no accident that such expressions as the following are still used today: the heart "thumps with fear", "jumps with joy", "stands still", and so on. Definite shifts have also been observed in the cosmonauts when studying the pulse rate (Table 2).

TABLE 2

	Basic pulse rate (average)	1st day of jumping		6th day of jumping		10 to 12th day of jumping
		Before flight	In airplane	Before flight	In airplane	Before flight
Gagarin	77	98	96	80	60	80
Titov	77	92	104	88	80	84
Nikolayev	70	100	120	88	76	88
Popovich	62	86	80	72	64	76
Bykovskiy	77	97	–	76	–	74
Leonov	56	71	90	–	72	80
Volynov	66	77	–	–	84	84
Khrunov	65	84	100	–	88	78
Shonin	70	89	–	–	96	–
Gorbatko	78	92	120	–	108	90

We see from the table that on the first day of jumping there is considerable increase of the cosmonauts' pulse rate prior to boarding the airplane and while in the airplane, which indicates considerable emotional excitement. The pulse reaction was considerably less on the following days. However, the pulse rate shifts continued until the end of the first parachute training stage. After landing, the pulse rates of the cosmonauts were very high — 170 - 192 beats per minute. For trained parachutists the pulse rate increased to a maximum of 136 beats per

minute under these same conditions. This indicates that for well-trained individuals parachuting does not cause any cardiovascular system activity shifts which exceed the limits of the variations which are noted after moderate physical exertion. The cosmonauts' pulse rate described above depended both on the as-yet-undeveloped skills in controlling the parachute canopy /151
and on the marked emotional stimulation. The largest pulse shifts (up to 192 per minute) were noted in Nikolayev and Popovich after a severe flat spin which developed during free fall. At the moment of landing, in addition to marked quickening of the pulse we noted emotional depression and sluggishness of movements. The parachutists did not respond immediately to questions.

In the case of honored master of sport N. K. Nikitin (2500 jumps), under the same conditions his pulse rate increased during free fall to 148 per minute (the pulse rate was recorded by a special instrument during free fall) and upon landing was 126 per minute. Our data on pulse rate during free fall are in agreement with the data of Grimak, who reproduced the emotional states of the parachutist in hypnosis.

Long ago, Lesgaft showed that only with the aid of practice can an individual learn to "isolate and compare the impressions received and at the same time train himself to observe, increasing his proficiency and ability to verify by analysis his thoughts and actions" (1952, p. 108). In his study on "Time Sense and Motor Reaction Speed", S. G. Gellershteyn showed experimentally that man can by training develop in himself the capability for determining time intervals precisely.

In the course of their parachute jumps the cosmonauts not only acquired motion coordination skills but also the ability to reproduce (measure) given time intervals in the free-fall period. Thus, while in the first delayed opening jumps they usually overestimated the time intervals (sometimes by a factor of two), in the subsequent jumps their errors did not exceed a second. /152

Thus, the pulse rate changes, changes in wrist strength, and also the inexact reproduction of time intervals disclosed in an objective fashion the emotional mood of the cosmonauts with regard to the coming jumps. These changes showed that on the first day of the jumps their reactions were quite significant, differing markedly from the reactions of well-trained parachutists. Later on, their reactions became more and more like those of experienced parachutists with 350 or more jumps.

The objective data of the study agreed with the psychological observations. The emotional state changes as a function of increasing number of jumps can be illustrated graphically by the psychological observations of Gagarin on successive jump days.

1st day. Prior to the first jump he showed excitement immediately after donning the chute. At this time he was somewhat anxious and talked very little, which was quite uncharacteristic for him. His gestures were restricted, his speech was subdued. After the jump was over his mood was elated, but tenseness was observed for another hour.

2nd day. Prior to the second jump he was less tense. He joked but tension could still be seen (Figure 13).

4th day. He jumped with a 10 second delay in chute opening. After leaving the airplane he bent over and obtained a stable body attitude. He opened the chute after 10.2 seconds. During

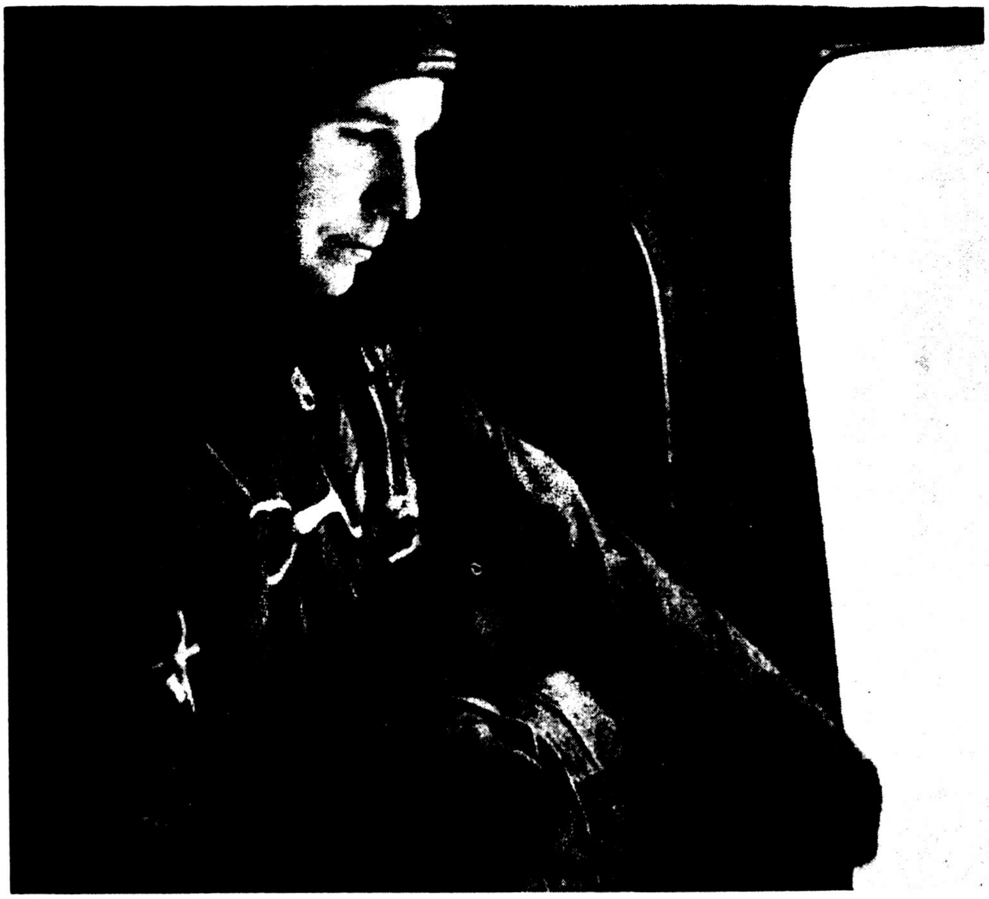


Figure 13. Gagarin prior to one of his first parachute jumps

the descent his actions were proper. Prior to the landing he turned in the harness to face downwind. After the landing he felt elated.

6th day. On the ramp prior to boarding the plane he was relaxed and good humored as usual. He joked a lot and talked with the medics. After the jump his mood was excellent. As always, he was in good spirits.

14th day. He completed the last jump of the first parachute training stage. He was relaxed on the ramp prior to flight. He controlled his body very well in the free fall. He opened his chute after 50.2 seconds. After the jump he was in excellent spirits.

Thus, Gagarin had excellent control of himself, seemed externally relaxed, showed himself a man of strong willpower and self-control. Throughout the training sessions he showed a combination of self-control and rapid assimilation of the required skills. Some emotional tension was noted only during the first two jumps.

The data presented above and the literature data as well show that the emotional manifestations begin to subside as a result of mental conditioning as the jumps are repeated. The parachutists become confident in themselves and acquire skills /154 in coordinating their movements in the free-fall period and the ability to estimate time accurately. However, we must note that in the case of repeated parachute jumps the emotional manifestations do not disappear completely even in experienced parachutists. In this case the fear emotions begin to have the nature of ssthenic, combative excitation, associated with activization of conscious activity. Such reactions to danger are characteristic only of humans and have a social nature. B. M. Teplov wrote: "Danger may quite indirectly cause an emotional state of the sthenic type, positively colored, i.e., associated with a sort of enjoyment" (1945). This situation can be illustrated to some degree by observations made of Popovich. During the first jumps he had good control of himself at the time of takeoff, but when the jump did not turn out well he was observed to have negative emotions. We shall present some data from the observations.

5th day. He made a jump with 15-second delay in opening the chute. Prior to the flight we was somewhat tense and unusually withdrawn. He was noticeably excited. He separated from the airplane without bending over. His body was unstable during free fall. He opened the chute at eight seconds. After landing he was again disappointed with the jump, which had not been entirely successful, and was obviously unhappy with himself.

6th day. He jumped with a 20-second delay in chute opening. Prior to the flight he was relaxed. As he left the airplane his body was bent only slightly. The fall was unstable for the first seven seconds. Then he took the correct body attitude and the free fall became stable. The time at chute opening was 20.2 seconds. After the jump he was happy and excited. He laughed and said he now understood the errors he had made in the previous jumps. His mood was cheerful and elated.

We see from these observations that Popovich's psychic status changed as a function of the quality of his jump. In his case the skills involved in free fall of the body in space and time reproduction were not formulated and consolidated immediately. Prior to the termination of the first stage of the training sessions he was able to discover the reasons for his problems, mobilize his willpower, and achieve good results in his jumping performance. After this his emotions were of a sthenic nature.

For all the cosmonauts the positive emotions were most stable in the second stage of the basic parachute training course. In this period the cosmonauts became composed and attentive prior to the jump. After the jumps in the second training stage, just as in the first stage, speech activity increased, feelings of relief and satisfaction with the jump just performed were noted. After his space flight Gagarin gave the following description of his emotional states during the parachute jumps: "During a short time period I made about 40 jumps. They were all quite similar to one another. Each jump was different, leaving every time a mixed feeling of excitement and pleasure. I enjoyed both the languor felt in the body prior to the jump, the anxiety, the excitement, and the violence of the jump itself. Parachute jumping hones the character, sharpens the will." /155

Considerable attention was also devoted to parachute training in preparing man for his sortie into open space. Just as in the case of parachute jumping, when going out into support-free space man must overcome spatial tension. We recall that Tsiolkovskiy foresaw such difficulties. The hero of his science-fiction novel "Away From the Earth", published in 1916, says: "When I opened the outer door and saw myself at the threshold of the rocket I felt faint and made a convulsive movement, which was what pushed me away from the rocket. I had already become accustomed to floating without support between the walls of the cabin, but when I saw that there was nothing below me, that there were no supports anywhere around, I began to feel faint and came to only when the entire chain had been unwound and I found myself at a distance of a kilometer from the rocket" (1960, p. 167). We see that the founder of cosmonautics assumed that exit from the spacecraft would involve overcoming the "fear of space". This is then the reason why the problem of training the higher emotional and will qualities occupies an important place in the cosmonaut preparation program. The degree to which this is justified can be judged, for example, by the following passage from Leonov's report: "As for the so-called psychological barrier, which was supposed to be an insurmountable barrier to an individual preparing to duel with the abyss of space, I not only did not sense any barrier but even forgot that there might be such a thing. There was no time to think about such a barrier. Those 20 minutes I spent in outer space, including 12 minutes away from the spacecraft, were the 'essence' of the Voskhod-2 flight. I understood this and did everything possible to make certain that not a single second was wasted." We note that the data from Leonov's self-observation corresponded fully to the objective recording of his physiological functions, which indicated the emotional state of the cosmonaut. His pulse and respiration rates did not exceed the values obtained during the training sessions in the airplane and in the altitude chamber. The timbre and intonation of his voice corresponded (as shown by spectral analysis) to positive, sthenic emotions.

The subjective speedup of time passage noted by Leonov in space can be related with positive emotions of sthenic nature. "To my great disappointment," he noted in his report, "the time assigned for work outside the ship flew by very fast. The entire period of stay in space seemed to last only one to two minutes." It is true that in this case the cosmonaut was not supposed to evaluate the passage of time and therefore he did not utilize any auxiliary techniques, which would have changed the situation. /156

Leonov's success in his spacewalk was no accident. At the moment he made his sortie into space, Leonov held the title of "instructor parachutist" and had made 117 jumps of varying complexity. As a result of the parachute training he was able to eliminate completely any "psychological barrier" between himself and support-free outer space.

Khrunov and Yeliseyev had to overcome a psychological barrier in transferring from one spacecraft to another. Khurnov was backup for one of the present authors on the Voskhod-2 flight. He was fully prepared for a spacewalk even at that time. But he had achieved this position only by means of considerable perseverance and persistence. He entered the cosmonaut ranks in 1960, physically strong and healthy, but had absolutely no athletic training. I recall our first excercise at the Central Army Sports Club. At that time he was afraid to jump from a three-meter tower into water. I thought at first that he was joking. But he stood frozen, holding on to the railing, afraid to jump. This was strange to see. Everyone else was jumping and suddenly he stood alone. But he began to train with perseverance and purpose. He suffered some bruises and went around black and blue, but he stubbornly continued to jump. He not only learned to dive well — that was not the main point. The main thing is that he managed to conquer his fear of height.

Later he made his parachute jumps successfully and completed several dozen jumps of varying complexity. In connection with an evaluation of the importance of parachute jumps in cosmonaut preparation, there is considerable interest in the self-observation of Khrunov during his sortie into space from Soyuz-5 and his transfer into Soyuz-4.

"My first job was to get out of the spacecraft orbital module. The hatch opened and sunlight flooded into the ship. I saw the earth, horizon, and black sky, and felt just like I did prior to leaving the airplane during my first parachute jumps. This excitement was like that experienced by an athlete before the start of a race and lasted several seconds. Then the work rhythm which had been developed in dozens of training sessions took over and I thought only of performing the mission."

In the preceding chapter we discussed in detail the importance of cosmonaut flights in airplanes for orientation in space and professional preparation. Here we shall simply note that the emotions of an individual flying an airplane depend not only on flight altitude, which always involves a potential danger, but also on airplane speed.

As a rule, during work activity on the earth an individual can perceive quite completely and clearly the objects which are necessary for his work, can grasp the situation which develops, can make a decision and perform some particular operation. During high-speed flight the time for all this is often not only limited, there may even be a shortage of time. B. S. Alyakrinskiy writes: "For flight activity it is characteristic that the time deficit is usually measured in fractions of a second, seconds, and only rarely in minutes, while under ground conditions the time deficit, if there is one, is usually of considerably greater length. Here we should mention the traditional 'student' time deficit of one day. It is obvious that making a correct decision during high-speed flight becomes possible only when the pilot has learned to estimate time intervals adequately and 'make the most of his time'." In many cases it is particularly important to be able to perceive micro-intervals. The professional activity of the pilot trains his time estimating sense. /157

It is very important that the cosmonaut have this sense highly developed, particularly since spacecraft control may often take place on the background of considerable emotional reactions, under conditions of limited time or time deficit.

ESTIMATING TIME INTERVALS UNDER ALTERED GRAVITY

We have already discussed the fact that the information arriving at the brain from the sense organs changes markedly in the weightless state. In this connection, there is considerable interest in the problem of adequate perception of time in this state. We conducted a series of two experiments in order to clarify this question in application to the conditions of brief weightlessness created in jet airplanes.

Sixteen individuals participated in the first series of tests. Their task was to estimate the time of exposure to the weightless conditions. During the test the subjects performed some other operation (writing test, rotation in the Barany chair, work with the coordinograph, movement in support-free space, and so on) which made it impossible for them to count mentally in order to measure the time interval. The accuracy of the time interval estimate under weightless conditions was recorded objectively by the doctor conducting the experiment or by the instructor pilot with the aid of a stopwatch. In all, there were 58 tests conducted in this series under weightless conditions.

As a rule, in the first flights those subjects who withstood weightlessness well underestimated the time of exposure to this unusual factor. They perceived an interval of 35 - 40 seconds as lasting 15 - 20 seconds. During repeated flights while performing the same task, the errors in underestimating the time interval decreased, which we believe is associated with good adaptation of the organism to the weightless state and marked decrease of the emotional tension. Conversely, the subjects who experienced unpleasant sensations under weightlessness estimated that the exposure interval of 24 - 26 seconds had /158 lasted a minute or more. Subjects who were restrained to the seat by the belt system estimated time under weightless conditions more accurately than those who were performing tasks in support-free space. This is explained by the fact that in support-free space the emotional feelings of the subjects were stronger (in connection with the more marked change of the afferent impulse pattern).

As an illustration we shall present the results of some observations. During his first flight, one of the present authors (Lebedev) felt that the 24-second interval in the first "hump" (when euphoria developed) flashed by instantly, while in the second "hump", when spatial illusions developed and there was negative coloration of the emotional state, the same interval seemed to last infinitely longer.

The cosmonauts and subjects who had considerable experience in weightless flight and withstood its action well perceived the passage of time quite accurately, even when moving about in support-free space. Gagarin wrote the following in his report on a weightless flight on November 30, 1965: "The sensation in flight was as usual. I did not observe any disturbances or peculiarities. The maneuvers were easily performed, coordination was normal." In three "humps" he estimated the 24 second intervals as lasting 22, 23, and 21 seconds. Gagarin withstood rotation in the Barany chair on December 1, 1965 quite well and described his emotional state as follows: "I felt fine, the sensations were normal. Everything was as usual during chair rotation." He estimated that the 26-second weightless period had lasted 24 seconds.

Some of the subjects, when rotated in the Barany chair under weightless conditions, developed spatial illusions and negatively colored emotional feelings, accompanied by overestimation of the time interval duration. For example, one of the subjects when rotated in the chair developed unpleasant sensations which had not occurred previously under weightless conditions. This weightless regime seemed extremely long to this subject. On the other hand, the same weightless time interval was underestimated by 2 - 3 seconds in the case of activity accompanied by positive emotions.

Subject P evaluated his sensations in this test as follows: "When rotating in the chair in the weightless state with my head down (eyes closed) I had the feeling that I was suspended head-down in a bent-over attitude." Rotation in the chair which lasted 10 seconds was estimated as a 25-second interval. Prior to rotation in the chair the time in weightlessness was estimated quite accurately (intervals of 24 - 26 seconds were estimated to be 26 - 28 seconds). /159

Fourteen individuals participated in the second series of experiments, and 87 experiments were conducted with them under weightless conditions. While in the first series of tests the subject's task was to evaluate the passage of a time interval, in the second series the task was to reproduce a 20-second interval under weightless conditions. In horizontal flight the subjects were able as a result of training to perform this task to within $\pm$ 0.5 seconds. They selected the mental counting technique voluntarily. The subject started and stopped the stopwatch himself without looking at the watch.

The results of the second series of tests involving the reproduction of a 20-second interval under brief weightlessness conditions are shown in Table 3.

TABLE 3. REPRODUCTION OF GIVEN INTERVAL IN LEVEL FLIGHT AND UNDER BRIEF WEIGHTLESS CONDITIONS

Subject	Tolerance to weightlessness	Coloration of emotional sensations in weightlessness	20-second interval reproduction time		Perception of time passage
			In level flight	In weightlessness	
S-v	Satisfactory	Negative	20.0	16 (2)	Slow
L	Poor	"	20.5	17 (9)	"
V	Satisfactory	"	18.5	19 (3)	Normal
B	"	"	20	20.5 (4)	"
S-o	Good	Positive	20	23 (8)	Fast
Ya	"	"	20	21.5 (3)	"
K	"	"	20.5	20 (6)	Normal
G	Satisfactory	Negative	23	21 (4)	Slow
R	Good	Positive	20	20 (8)	Normal
Sh	"	"	21	20.5 (8)	"
Ch	"	"	20	22 (14)	Fast
Shch	"	"	20	19.6 (7)	Normal
S	"	"	20	20 (5)	"
Kh	Excellent	Normal	20	20 (6)	"

Note. 20-second interval reproduction time given as arithmetic mean value — number of experiments in weightlessness shown in parentheses.

We see from the table that the subjects can be divided into three groups on the basis of how they perceived time subjectively in the weightless state: with normal, slow, and fast perception of time passage. Eight of the subjects perceived the passage of time under weightless conditions as normal. This group included those whose estimate of the time interval in weightless conditions differed from the estimate of the same interval in horizontal flight by no more than 2 seconds. Two of these subjects had emotional feelings with negative coloration, the others had positive feelings. In the group with slow perception of time passage in weightlessness, consisting of three individuals, there were premature actions, expressed in premature stopping of the stopwatch, associated with overestimation in the mind of the time interval which had passed. All three had negative coloration of the emotional sensations along with satisfactory or poor tolerance to parabolic flight.

Quickened time passage in the mind was noted for three of the subjects under weightless conditions. This showed up in delayed actions, since the time interval passed was underestimated mentally by these subjects. They all tolerated weightless flights well and experienced positive emotions in the course of these flights.

Evaluating the experiments, subject B wrote: "During the first flight the time sensations were somewhat altered in the quickening direction, but only during the first five seconds. Thereafter the passage of time remained the same as on the ground...."

The results of statistical analysis of the data from the first group are shown in Table 4. /160

As we would expect, in the group with conventional perception of time passage under weightless conditions the deviations from the basic data are statistically unreliable (confidence level /161 less than 10%). In the group with slow perception of time

TABLE 4. RESULTS OF STATISTICAL ANALYSIS OF DATA ON TIME REPRODUCTION UNDER WEIGHTLESS CONDITIONS

Time passage perception in weightlessness	Number of subjects	Number of experiments	X	σ	m_p	t	Confidence level, %
Normal	8	47	0,02	±0,35	±0,5	0,04	< 10
Fast	3	25	2,3	±1,04	±0,2	11,06	> 99
Slow	3	15	3,4	±1,30	±0,3	11,33	> 99

passage under weightless conditions the deviations in the direction of overestimation of the time intervals were significant: their reliability is above 99%. The reliability of the deviations in the group with quickened perception of time passage was also more than 99%.

In the preceding chapter, when discussing the role of the semicircular canals for orientation under weightless conditions, we said that the perception of time is associated with the perception of space. In this connection the self-observation of research doctor I. F. Chekirda, who observed an interesting phenomenon, is to the point. Here is the relevant passage from his self-observations: "In one of the first weightlessness simulation flights I noticed that the subject when performing the Coriolis test shortened the time of trunk tilting and the intervals between these maneuvers and I commented on this to him. When analyzing the recordings of the physiological functions I found to my surprise that the time for performing the experiment corresponded to the program and did not differ from similar experiments in level flight. I came to the conclusion that there had been a change of my estimate as an experimenter of the duration of the movements under the weightless conditions."

In the series of experiments described above all the factors which influence the change of the estimate of the time interval passed act essentially separately. But we know that in actual space flight these factors act together. This led to the necessity for conducting experiments to evaluate the 20-second time interval estimate in an actual space flight. This experiment was performed by Titov. Each test consisted of 20 measurements. After starting the stopwatch the cosmonaut began to count off 20 seconds in his mind and stopped the watch on the basis of a subjective estimate of the given time interval. The results were entered in the ship's logbook. We shall present the arithmetic mean values of these results for four tests, conducted in the spacecraft simulator when "running through" the flight plan and in orbital flight (from data of Lebedev) (Table 5).

TABLE 5. REPRODUCTION OF 20-SECOND TIME INTERVAL BY TITOV IN SPACECRAFT SIMULATOR AND DURING SPACE FLIGHT

Location	Time of day			
	Morning	Midday	Evening	Night
Spacecraft simulator	20.8	20.2	20.0	21.0
Space	20.3	20.2	20.1	20.1

Thus, under conditions of brief weightlessness the disruption of time perception in the first flights can probably be explained by marked change of the information reaching the brain from the skeletomuscular apparatus, the otolithic instrument, and the other organs, and also by the emotional state of the subjects. In all the cases of subjective quickening of time passage the subjects felt pleasant emotional feelings. For these subjects the time passed unnoticed (fast), which led to delayed actions in reproducing the given time interval. In the case of subjective slowdown of time passage all the subjects (without exception) experienced unpleasant sensations. They overestimated the time intervals which had passed, which led to premature reaction. /162

For the subjects with positive emotions the performance of tasks under weightless conditions increased the errors in estimating the time interval passed in the direction of underestimation since, on the one hand, the subjects did not have a chance to concentrate on estimating the time and, on the other hand, the increased emotional tension led to increased stimulation in the brain cortex. The reverse pattern occurred in the case of negative emotions.

On the one hand, the experiments conducted confirmed the theoretical ideas on the dependence of time perception on the individual's emotional state and, on the other hand, they make it possible to state that with proper training man is capable of reproducing time accurately under the unusual conditions of weightlessness.

Of particular importance is the study of time perception by the cosmonauts under positive load factor (acceleration) conditions. We have long known from aviation experience that accelerations lead to disruption of the visual perceptions, alter markedly the motion trajectory, lead to increase of the number of errors in solving very simple arithmetic problems, increase of the response motor reaction time in proportion to the increase of the acceleration, and so on. A summary of the data characterizing the change of man's psychic activity under positive load factor conditions has been presented in a study by Platonov (1960).

Since the orientation in time is very important in controlling a spacecraft under positive load factor conditions, together with N. Kh. Yeshapov we conducted some relevant experiments.

The study was made on subjects while rotating in a centrifuge to create at 10-g acceleration in the chest-spine direction. /163

After transmission of a signal (we used a conventional airplane indicator lamp with red light filter), the subject was to count off mentally a ten-second interval and then use his thumb to depress a button (the thumb motion was perpendicular to the direction of the vector of the effective load factor). He performed similar actions prior to load factor onset and immediately after stopping the centrifuge. Electrophysiological apparatus was used to record the response. The moment the signal light came on and the moment the subject depressed the button were noted on the tape. At the same time recordings were made of the dynamics of the subject's basic physiological functions (electrocardiogram, electroencephalogram, respiration, and other functions), and observations were made using a television system.

In all there were 10 individuals involved in the testing and 172 counts of ten-second intervals were made. Of these, 40 were made prior to rotation in the centrifuge (in the cockpit), 60 were made while the load factor was acting, and 74 were made after stopping the centrifuge. The summarized data on the estimate by the subjects of the ten-second intervals are shown in Table 6.

TABLE 6. SUMMARY DATA OF REPRODUCTION BY SUBJECTS OF TEN-SECOND TIME INTERVALS

	Prior to rotation in centrifuge	With action of load factors		After termination of action		
		Up to 4-g	From 4 to 10-g	1 min.	2 - 3 min	After 3 min
Arithmetic mean	9,98	10,41	10,8	10,39	10,20	10,44
Estimate of mean standard error	±0,12	±0,22	±0,32	±0,34	±0,22	±0,23
Limits of confidence interval (P=95%)	9,75—10,24	9,96—10,86	10,15—11,45	9,70—11,08	9,74—10,66	9,98—10,90

This table is compiled from the absolute values of the time estimate. We see from the table that deterioration of the time interval reproduction accuracy is noted while the load factor is acting, and also during the aftereffect period. Along with the tendency toward increase of the reproduced time interval, there is a quite marked broadening of the range of erroneous /164 estimation of the ten-second time interval. Particularly large deviations were observed during the action of large load factors (for 4 to 10 g) and during the first minute after rotation. The following data give a good idea of the large scatter in determining the ten-second interval:

Number of measurements in the time intervals	Before rotation	Up to 4-g	From 4 to 10-g	1 min after rota-tion	2-3 min after rota-tion	More than 3 min
6,6—7,5			1			
7,6—8,5		1	2			
8,6—9,5	12	6	4	9	5	7
9,6—10,5	22	10	7	9	7	8
10,6—11,5	4	5	7	4	5	11
11,6—12,5	1	4	5		2	3
12,6—13,5	1	1	2	1		1
13,6—14,5			2	1		
14,6—15,5			1			
15,6—16,5	40	27	31	25	19	30

From these data we can evaluate approximately the accuracy of the time estimate. While prior to rotation half the measurements fell in the ± 0.5 second range, with a load factor of 4-g the number of error estimates with this accuracy decreased by a factor of 1.5, and with a load factor of 10 g — the number decreased by a factor of 2.6. During the aftereffect period the time estimation accuracy increases somewhat, but still remains lower than that found prior to rotation by a factor of 1.5 - 2.

We note that some subjects constantly underestimated or overestimated the ten-second interval prior to rotation in the centrifuge. For example, three subjects underestimated the time interval while another three subjects overestimated the interval. For the remaining four subjects the error of the subjective time passage oscillated in the 1 second range, i.e., did not exceed the limit of the oscillations noted under normal conditions.

During the time of rotation all the subjects showed a tendency toward increase of the interval being reproduced, i.e., to subjective quickening of the passage of time. The dynamics of the ten-second interval estimates in comparison with the background values (obtained in the cockpit) are shown in Table 7.

In comparison with the data presented in Table 6, the changes have the same tendency toward increase of the time interval being reproduced and significant spread of the indices

TABLE 7. DYNAMICS OF TEN-SECOND INTERVAL REPRODUCTION WITH LOAD FACTORS ACTING

Index	With load factors acting		After stopping centrifuge		
	Up to 4 g	From 4 to 10 g	1 minute	2-3 minutes	More than 3 minutes
Changes in comparison with initial values (in cockpit)	+0.41	+o.44	+0.42	+0.18	+0.64
Estimate of mean standard error	±0.16	±0.37	±0.38	±0.23	±0.17

under action of load factors from 4 to 10 g and at one minute after stopping. We note not only increase of the reproduced interval during action of the load factors (for example, with load factor up to 4 g the confidence range t = 2.6), but also in the aftereffect period, 3 - 5 minutes after stopping the centrifuge (the increase of the reproduced interval in comparison with the initial values is reliable with t = 3.85). /165

These results make it possible to conclude that there is disruption of time perception in the direction of underestimation under the action of load factors. Along with the overall quickening of the passage of time, we note considerable scatter of the reproduced ten-second interval.

At the present time we are not able to explain this pattern of time perception under the action of load factors. This question needs further experimental study.

TIME PERCEPTION IN THE CASE OF SENSORY ISOLATION

Under the conditions of extended space flight man encounters not only emotional stress, weightlessness, and accelerations, but also the phenomenon involved with limited influx of information (stimuli) from the external medium. This also gives rise to several complex problems.

As a rule, on the earth various natural patterns and creations of man's handiwork pass one after another before our eyes. All sorts of sounds act on the hearing organs constantly and create an audible background. The skin receptors sense temperature changes and movement of the air. The information concerning all such influences of the surrounding medium are transformed into nerve impulses and arrive at the brain. However, by no means all of this information is recognized. While performing various functions, the subthreshold stimuli, in particular, serve as a source for exciting the subcortical formations, which provide the best perception of the actual situation surrounding /166
the individual, supplying the working segments of the cortex of the large hemispheres with the required amount of energy.

Various disruptions of brain functioning may develop in the absence of a definite stimulus minimum. For example, the well-known Russian therapist S. P. Botkin described in the 19th century a patient who had no forms of sensitivity other than the cutaneous, and that only on one hand. Usually this patient was asleep and awakened only when touched on the hand which retained sensitivity. Pavlov observed a patient who, as a result of trauma, had of all the sense organs only one eye and one ear. If his eye was covered and his ear was plugged, which were his windows to the outside world, he immediately fell into a deep sleep.

After conducting many tests on dogs in a "tower of silence", Pavlov came to the conclusion that for normal operation of the cerebral cortex it is necessary to have constant charging of the cortex by nerve impulses coming from the sense organs through the subcortical formations. The uniformity and monotony of the impressions in the absence of a sufficient quantity of external stimuli reduces markedly the energetic level (tonus) of the cerebral cortex, which in certain cases may lead to disruption of the psychic functions.

Such a situation is typical under spaceflight conditions. When the engines are shut down the cosmonauts enter the "kingdom" of silence. The cosmic silence, when there is no radio transmission, is disrupted only the the weak and uniform noise of the operating electrical equipment. It is not just by chance that the concept of "sensory deprivation", characterizing the severe lack of stimuli, has arisen in space psychology.

It is true that aviation doctors and psychologists have encountered this problem even prior to space flights, when the "ceiling" of aviation rose to several thousand meters. Thus, foreign scientists studying the behavior of pilots operating high-altitude single-place airplanes and balloons found that at altitudes from 10 to 25 thousand meters and above, about

25 - 35% of the pilots experienced a "feeling of separation from the earth." Half of them reported that this feeling was pleasant and manifested itself in a "special sensation of exultation, desire to continue the flight forever". The other half, conversely, reported that the sensation was frightening. The pilots reported that during high-altitude flights "their senses were separated from their bodies", as if they "were in a different world", and movement in space was accompanied by auditory and visual hallucinations. All this was explained by the marked reduction and also the monotony of the stimuli acting on the nerve system.

However, in the period of man's preparation for the first space flights science did not yet have sufficiently complete information on the influence of "sensory deprivation" on the organism. Therefore, space psychology and medicine were faced with the problem of studying the cosmonaut's capability to work under conditions of uniformity and monotony of the impressions and the absence of an adequate influx of stimuli from outside. /167

In one series of experiments the foreign investigators placed the subjects in individual boxes on comfortable couches. Their eyes were covered with glasses which reflected the light, their ears were covered with audiphones which made it impossible to hear even one's own speech, and the extremities were covered with housings which excluded tactile perceptions. The experimental subjects took food and performed their physiological functions when necessary. In another series of tests, marked limitation of the external stimuli influx was achieved by immersing the subject in a special outfit into tanks filled with water. This made it possible to provide isolation not only from sources of light and sound, but also from influx of the usual information associated with support on the surface of the earth and with tactile sensations.

As a result of such experiments it was found that the reactions of the subjects are expressed basically in the appearance of a sort of feeling of "hunger" with respect to external impressions. In many cases this led to motor agitation. In the course of the first few hours the subjects relived the events of that day, thought about themselves or their friends. Then they began to experience a more or less marked sensation of "pleasure" from the experiment, which was quickly replaced by a rapidly increasing requirement for stimuli from the outside. To satisfy this desire some of the subjects pounded on the walls of the box, exercised their muscles (in the water), made swimming motions, pushed one hand against the other. However, if they were able to suppress the requirement for stimuli and remain in a quiet state, a sort of inner concentration come over them. Now the subject's sense of time became disturbed. They worried about the absence of a clear-cut idea of whether they were asleep or awake. Then came a period of fantasizing and the development of hallucinatory phenomena. Most of the subjects refused to continue the experiment after 24 - 72 hours.

In the USSR the experiments with stimuli limitation were carried out using a somewhat different technique. The subjects were placed for several days in an isolation chamber, where a definite number of hours were assigned for work simulating operator activity, while the subjects were left to themselves the remainder of the time. This situation corresponded better to actual space flight. The studies made using this technique under the direction of F. D. Gorbov showed that a healthy /168
individual with high morale and strong willpower can stay in the isolation chamber for a long time without any psychic changes which threaten his health and can regain his capacity for work. However, the subjects do develop sensory illusions. Specifically, together with O. N. Kuznetsov, we found: illusions

associated with incorrect recognition of stimuli, the informational nature of which was insufficient for precise perception; subjective interpretation of dreams as reality; eidetic images; formation of "super-valuable" ideas; disruptions in the emotional sphere, and other phenomena.

Along with the broad range of studies of work capacity and physiological and psychic functions, together with A. N. Litsov we carried out experiments in the isolation chamber to study time perception under these conditions.

But before presenting the observations themselves we shall discuss some facts concerning time perception under isolation conditions from literature sources. In this regard, the experiments of the French speleologists using deep caves in place of isolation chambers are of interest. Thus, in 1962 Michel Siffre spent two months in a cave. We see from his report that "the time sense quickly disintegrates" for the subject under conditions of solitude and absence of connection with the external world. After 1000 hours (more than 40 days) it seemed to him that only about 25 days had passed. And when the unusual experiment terminated and his friends came for Siffre, he said: "If I had known that the end was so close I would have eaten up the rest of the tomatoes and fruit long ago."

Three years later the experiment was repeated by another Frenchman — Antoine Senier. On the 122nd day of his stay in a cave the subject was amazed when he was told on April 2, 1965 that the experiment would soon be over. According to his reckoning it was the sixth of February.

Another investigator, the Englishman Lefferiti, who spent 130 days in an underground cave in complete solitude, also erred in his estimate of time. When he was asked prior to the termination of the experiment: "What is the date today?", he replied: "The seventh of July". Actually it was already the first of August.

Also of interest is the record prepared by the research doctor Ye. I. Gavrikov, who spent 45 days in an isolation chamber together with S. P. Kukishev. On the 32nd day of the experiment he wrote in his diary: "Siffre is right, of that I'm certain. The loss of memory is a strange thing: yesterday I could not recall what I had to eat the previous evening. This seems to be a stable phenomenon. Past days just disappear from the memory. I am reading Siffre very carefully and slowly, more so than before. I find much in common in the sensations, although the conditions are different. The same sort of forgetfulness. Past days become something abstract....

"We are in complete agreement concerning time. Time flies /169 fast, as if it were rushing into a chasm, I cannot recall what was, it simply disappears."

In our experiments on long-term isolation under silent chamber conditions the subjects also noted subjective quickening of time passage. Thus, subject A, an engineer by profession, wrote the following in his diary on the second day of the experiment:

"5 December 1963. It is interesting how my ideas on the scheduled stay time change: yesterday it seemed to me (after the first day had passed) that the scheduled stay time would be terribly long, but today everything is falling into place and the scheduled stay time doesn't seem so long now. But this is only the second day — we'll see what happens later on.

"7 December. I find it difficult to say why, but today passed very quickly (possibly because Saturday always passes fast).

"8 December. The day went quite fast.

"10 December. Everything is going like the planned schedule. Up till lunch time the time files by. From lunch to dinner time the time passes slowly, really until somewhat later, until recording of the physiological functions after dinner. And after this the time again flies by, particularly when I am busy with something. It's true that I don't make a great effort to think up things to do. I only do what I want to. In this way the time passes fast and you enjoy what you're doing. And if I don't want to do something, I prefer to just sit down or walk around and think. There's always something to think about, particularly when there's no one to interfere.

"12 December. The ninth day has passed. This is the last day, the tenth day. My mood is just as good as yesterday, but to be honest I have not noted any particular lift. True, once in a while the thought flashes by that this is the last day, but for some reason or other this doesn't cause any wild joy. Today has passed very rapidly, I noted its passage only when I was eating."

Subject L, a pilot by profession, writes in his diary:

"12 July 1967. Fourth day of the test. I feel fine but a little fatigued. Obviously I have not yet adapted to the new agenda. During the day my work capacity was good. I get the impression that the agenda conceals some time. It would be interesting if one could write one's own agenda or even live without any agenda at all.

"13 July. The passage of time is hardly noticeable. It's hard to believe that I've spent five days in the isolation chamber."

When conducting our studies in the isolation chamber we used both the conventional regime and shifted ("inverted") and fractional regimes. Subject B wrote the following in his diary concerning the subjective passage of time for the fractional work-rest regime:

"18 November 1967. Second day. Time passes as usual. No /170 negative emotions other than some chagrin that I am not doing everything correctly. During my first free time I'm going to prepare a detailed agenda.

"23 November. The fractional regime reduces considerably the feeling of long days. In place of days there are three toy-like segments of time: you jump up, stick the electrodes on, play a few games in the dark, eat a bit, write a few lines, and back to sleep. Three such cycles and no days at all. For me the four days of the fractional regime passed nearly as fast as the first two days of the normal regime. One gets the feeling that several bits of time have simply been cut out of the days and thrown away.

"24 November. After I got used to the fractional regime the time goes faster, more precisely the rate is the same but the days seem shorter by a factor of 1.5. Eight days have now passed. Of these the last four have passed easier and faster than the first four.

"26 November. Had a really good sleep last night. Since morning I have had the sensation of normal passage of the time of the day. I got the feeling that I am just here resting from the worldly bustle. From the previous experiment there remains only a general shortening of the scale perception of the day as a whole; under normal conditions a day is full of activities and impressions. Days in the isolation chamber are condensed like milk in a can. They are far less emotionally distinct."

In addition to the subjective estimate of time, together with A. I. Litsov we carried out experiments in the isolation chamber involving the reproduction of given time intervals. The complex of time tests was carried out in a quite definite sequence: a three-fold 20-second test (beginning and end of interval indicated by closing the hand with recording of the myogram), three-fold 20-second test with parallel performance of arithmetic operations, and three-fold 20-second test in the process of professional operations in the simulator involving control of the spacecraft. Prior to this the subjects had worked out the reproduction of the 20-second interval over the course of a long time period (up to a year or more) in the process of the parachute jumps. Then training sessions involving the reproduction of the given interval using a stopwatch for control were carried out for two days immediately prior to the isolation test. The subjects practiced in the course of the experiment with the aid of a clock with a sweep second hand installed in the isolation chamber.

Analysis of the results obtained showed that the reproduction of the given interval (20 seconds) undergoes definite changes under isolation conditions. These changes (although small) showed up even in the period of preparation for the experiment. On the very first day of isolation in the chamber the subjects were divided up in accordance with the plan into three groups. In the first group (30% of the participants) we placed those subjects for which increase of the reproduced interval was observed, i.e., subjective quickening of the passage of time. Thus, subject P reproduced the 20-second interval as a 30.5-second interval. In the second group (15%) we placed the individuals for which gradual shortening of the reproduced interval was observed, i.e., subjective slowdown of the passage of time; in the third group of subjects (55%) we included individuals with alternate shortening and, or, lengthening of the reproduced intervals. /171

Such a distribution obviously reflects the nature and magnitude of the effect of isolation on the neuropsychic sphere of the subjects. In addition, there were three clearly marked periods of maximum stress, accompanied by maximum deviations in the time interval estimate — beginning, middle, and end of the experiment. The duration of each of these periods was from 12 hours to two days. Psychologically, this periodicity of the stress in the course of the experiment is associated with adaptation of the personality of the subject to the new situation. The initial period is characterized by an orientative reaction, getting accustomed to the conditions of solitude, involvement in the operator activity. This is replaced by a stable work stage. We believe that the common practice of dividing a lengthy, monotonous, forced activity which has concrete, established activity spans into two parts leads to the period of tension in the middle. The latter is subjectively experienced as a sort of turning point, which forces the subject to somehow evaluate the first half of the experiment and ready himself for the concluding stage of the same activity. The duration and degree of manifestation of experimental tension is different for different individuals and may be practically unnoticed in particularly active and well-composed individuals. After the turning-point period the activity again proceeds in a stable regime. The tension of the concluding period is caused by expectation of the end of the experiment and emotional anticipation of return to normal life. The subjects now perform only the scheduled activity and during the remainder of the time summarize their work, gather things up, or switch randomly from one activity to another.

TIME PERCEPTION AND ELECTROMAGNETIC FIELDS

> The creatures of the earth are the work of a complex cosmic process.
>
> V. I. Vernadskiy

The flights of Soviet Lunnik spacecraft have established that the moon has no marked electromagnetic field. Therefore, the magnetic compasses to which we are so accustomed on the earth will be of no use to lunar travelers in orienting themselves on the surface. The cosmonauts will have to determine their location from the celestial bodies or utilize instruments which act on different principles. But this is not the main problem. The main factor is that the earth's electromagnetic field will no longer act on the cosmonauts during their flights to the moon and while they are there. /172

We know that all living creatures inhabiting the earth have developed under and are constantly subjected to the action of electromagnetic fields and radiations of all the frequency bands known to us — from slow periodic variations of the earth's magnetic and electromagnetic fields to gamma rays.

At the present time the influence on the organism's life activity of electromagnetic radiations in the range from infrared to ultraviolet (photobiology) and from x-rays to gamma quanta (radiobiology) has been quite thoroughly studied.

However, the influence of the earth's geomagnetic field on the physiological and psychic processes has not yet received adequate study. Therefore, in describing specific reactions to change of the earth's electromagnetic field we shall limit ourselves to a phenomenological description of the phenomena, discuss certain hypotheses, and present the relevant experimental data.

The German psychoneurologists turned their attention comparatively long ago to the fact that during the period of magnetic storms, when the intensity of the geomagnetic field begins to change rapidly, the number of neuropsychic patients and their death rate begin to increase. These data were obtained in a study of 40,000 medical records covering a five-year period (1930 - 1935). Similar studies were made in the 1960's in the USA. They also confirmed that the number of neuropsychic patients and their death rate increase during the period of magnetic storms (Figure 14).

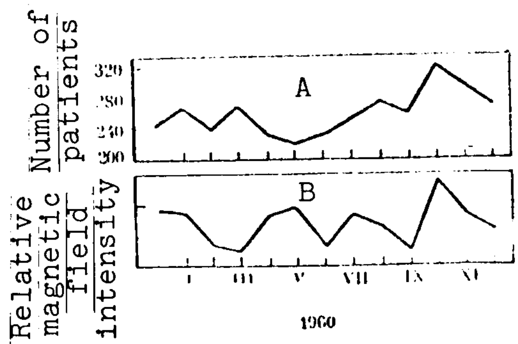


Figure 14. Neuropsychic patient hospital admissions in 1960 (A) and geomagnetic field variation for the same period (B)

Of considerable interest in this regard are the studies of V. Desyatov, who analyzed the dynamics of suicides and automobile accidents from 1958 to 1964 in relation with powerful eruptions on the sun. The latter cause very strong magnetic storms on the earth. Desyatov writes: "We find that individuals with a weak type of nervous system, and also chronic alcoholics, feel extremely depressed after solar eruptions. As a result, the number of suicides two days after solar eruptions increases by a factor of four or five in comparison with quiet-sun days. Reasons for suicides which appear insignificant on quiet-sun days sometimes become insurmountable in the days following solar eruptions.

The number of automobile accidents also increases two days following solar eruptions — by nearly a factor of four in comparison with quiet-sun days."

Observations of this sort are attracting increasing attemtion /173 among scientists. A large amount of information is appearing in the scientific literature at the present time on the influence of artifically created electromagnetic waves on the central nervous system of animals and humans, and also on the intracellular protein molecules. Thus, American investigators have subjected patients to the action of centrimeter radio waves. When the temporal part of the head is irradiated the subjects begin to hear noises which seem to be localized in the cervical region. Marked beharioral change of a monkey was observed when irradiated with metric waves: initially the animal became more alert, then fell into a deep sleep, but after some time awakened in an excited state. In the case of electromagnetic field (50 mHz) action on the temporal, frontal, and cervical regions of the head of dogs it was found that the conditioned salivation reflex increases by a factor of two or three, and differentiation is disrupted in animals with a strong type of nervous system. Under the influence of a constant magnetic field with an intensity of several thousand Oersteds, the motor activity of mice increased by about 50%. But a considerably more effective influence was observed in experiments with birds of the sparrow family. Their motor activity increased by a factor of 3.5 - 4 in comparison with control birds, and even by a factor of 10 in the evening hours. The magnetic field increases the motor activity of fishes by 64%.

An avoidance reaction was observed in the golden hamster and dogs under the influence of low-frequency electromagnetic fields. Ants subjected to three-centimeter waves begin to orient their whisker antennas parallel to the magnetic lines of force.

A large number of experiments with different animals (see the monograph on this subject by Kholodov, 1966, and that of Presman, 1968) have shown convincingly that electromagnetic fields influence the nervous system of the various aniamls and cause different physiological and behavioral reactions. In these same experiments it was found that in many cases these re- /174
actions depend very little on the energetic characteristics of the electromagnetic field acting.

In recent years many attempts have been made to explain the effect of electromagnetic fields on various forms of animals and on humans. We know that informational interactions, along with the energetic interactions of living creatures, play a significant role in the biological processes. Such interactions are characterized by information transformation (coding), information transmission, and elicitation of physiological reactions. The biological effects caused by these interactions depends not on the magnitude of the energy introduced into a particular system, but rather on the information introduced into the system. The signal carrying the information causes only a redistribution of the energy in the system itself, controls the processes taking place in the system. If the sensitivity of the receiving systems is sufficiently high, the information transfer can be accomplished with the aid of very little energy.

Presman considers that the reaction of animals to changes of the earth's electromagnetic field is associated with those biological systems which were formed in the evolutionary process for reception of information from the surrounding medium. He writes: "periodic changes of the natural electromagnetic field of the ambient medium have a regulating influence on the functioning of living nature — on the rhythm of the basic physiological processes, on the capability of animals to orient themselves in space, on the reproductive processes in populations, and so on. In the living organism the systems for the reception of information transmitted by the electromagnetic field are reliably protected against natural electrical interference...." (1968, p. 10).

On the basis of the hypothesis of the synchronizing influence of the natural, periodically varying electromagnetic field on living organisms, it is not difficult to explain the increase of the number of neuropsychic illnesses, suicides, and accidents during magnetic storms. The randomly varying frequency of the earth's magnetic field oscillations can impose on the biological processes rhythms which are not characteristic of these processes, i.e., can introduce into the organism, in Presman's words, "adverse" information. In the healthy individual the nervous system adapts well to changes of the surrounding medium. But in the case of nervous disorder or exhaustion the system becomes excessively sensitive to inputs from the outside. The weakened nervous system cannot cope with the increasing load (including perturbations of the geomagnetic field), and as a result nervous breakdown develops or there is aggravation of previously existing illness.

It has been established in various studies that electric potentials distributed in a definite pattern are present on the surface of the body of animals and humans. According to R. E. /175

Becker, this distribution is the result of the directive nature of the electron current along the nerve fibers. It has also been suggested that the system of bioelectromagnetic potentials may interact with variations of the earth's electromagnetic field.

In connection with the advances of "molecular biophysics", it is now thought that it is necessary to first study electromagnetic field biological action at the molecular level and only then approach the explanation of its effect on highly organized systems such as animals. However, it seems to us that we must agree with Presman, who considers that the reverse route is the realistic way to examine electromagnetic field influence on living organisms: start from the reactions of the entire organism to electromagnetic fields, then clarify to what less complex level of organization it is possible to trace those changes which in the final analysis cause the given reaction of the organism. It seems to us that Presman's example illustrating this hypothesis is quite apt. We know quite well from physics that a specific property of a resonant circuit is its particularly high sensitivity to an electromagnetic field of a definite (resonant) frequency. No one will deny that the electromagnetic oscillations induced in the circuit are connected with microprocesses — motion of electrons in the conductors and polarization of molecules in the condenser dielectric. But attempts to disclose the resonance mechanism at this level will be in vain — it is simply not there. Nor are these properties detected when examining the processes in individually taken macroscopic elements of the circuit — the condenser and the induction coil. The resonance property is inherent only to the entire organized system — the circuit as a whole.

We have already noted that each organ of a living organism has its own rhythmicity when isolated from the organism. All these different rhythms of each organ are synchronized in the organism as a whole. For example, in experiments with isolated heart muscle cells it has been found that while each cell has its own individual pulsation rhythm the aggregate of the cells pulses with a single frequency, which is set by the "leader cell", having the highest pulsation frequency. At the level of the higher animals the central nervous system acts as this synchronizing and regulating apparatus.

M. Breize suggested that rhythmic brain activity, which is accompanied by definite bioelectric events, performs the role of synchronizer of the behavior of all the processes in the central nervous system itself. According to many electrobiologists (Wiener, Guddi, Golubarg, Enlicher, and others), this rhythmic activity is apparently also the reference for the rhythm which defines the periods of cardiac activity, respiration, /176
motor actions, and so on. It is no accident that there are in the electroencephalogram characteristics known as stationary time series. It should be noted that this viewpoint is not shared by all scientists.

Regulation systems whose functioning is associated with electromagnetic oscillations are encountered in the most varied organisms. D. Woolridge writes: "In the nervous systems of the lower animals we can find many examples of neuron chains which generate periodic signals for regulation of the rhythmic functions of the organism.... We find an interesting example of a neuron oscillatory chain in the lobster. This chain consists of nine neurons connected into a ring and generates electrical impulses which control contraction of the heart.... The singing of the cicada is determined by an oscillator located in the brain of the insect" (cited in Presman, 1968, p. 213).

Examples of this sort could be multiplied by showing the complex system for electromagnetic regulation of the heart's rhythm in the vertebrates, and also the influence of the brain's electromagnetic vibration patterns on animals' physiological process rymthmicity and behavior. We shall discuss here the following aspect.

We have mentioned previously that many scientists have suggested that the brain's bioelectric activity is a sort of "biological clock". In studies made in the last decade it has been found that micropulsation of the earth's magnetic field takes place in the range from 0.01 to hundreds of Hertz. Becker noted that these pulsations are most marked in the 8 - 16 Hz range and suggested that it is the influence of this pulsation which is associated with the presence of the basic brain biopotential rhythm — the alpha rhythm — which has this same frequency.

Electrophysiological studies show that the alpha rymthm disappears in the somnolent state and appears only in the form of bursts when stimuli are activated. The studies of Voronin and Konovalov have shown that time "reckoning" does not stop in this case. On this basis they concluded that it is possible that there are two or more rather than a single oscillator in the brain and that these oscillators interact with one another so that they can reckon quite precisely any time intervals in the different functional states of the organism (wakefulness, somnolence, sleeping, and so on). In fact, during sleep slow waves appear on the electroencephalogram in place of the alpha rhythm.

Somewhat later Heron discovered in the waveband of the earth's electromagnetic field marked range of micropulsation frequencies (from 0.029 to 0.031 Hz), which correspond to the superslow brain potential oscillations. It is obsious that the correspondence of /177 the brain potential oscillations with the earth's electromagnetic field pulsations is not proff of direct connection between these two phenomena, but at the same time this coicidence suggests conducting experiments directed toward clarification of this question.

To check the hypothesis of the influence of brain potential change on time perception, we made the following experiments together with O. N. Kuznetsov and A. N. Litsov.

The eight subjects developed skill in reproducing a five-second time interval. The skill was considered developed when the subject did not make errors exceeding the limits of ± 0.5 second. During the course of the extended isolation chamber experiment the subjects were posed the task of reproducing this time interval four times a day (in the morning, daytime, and evening hours). Each study was made using the following program. After emplacing the electrodes, on the background of an unchanged electroencephalogram the subjects reproduced the five-second interval three times without the application of stimuli. The accuracy of the time interval reproduction was recorded on a strip recorded by contraction of the wrist with simultaneous recording of the electroencephalogram. The next three intervals were reproduced on the background of photostimulation with a frequency of about 10 Hz. This frequency was close to that of the alpha rhythm. Then displayed light stimulus rhythm frequency was reduced to 3 Hz and subsequently increased to 30 Hz. At each of these frequencies the reproduction of the given time interval by the subjects was repeated three times. Then the experimenter began to alter the stimulus frequency from 30 to 3 Hz without any particular pattern, making both smooth and abrupt changes. The subject also reproduced the given time interval three times with change of the photostimulator flashing frequency. In several cases a very clear intrusion of the alpha rhythm in the 3 - 10 Hz band of the displayed stimuli was observed. This intrusion was noted most often in the evening and nighttime hours, which can apparently be associated with the onset of fatigue.

These experiments showed that the reproduced time interval depended directly on the frequency of the displayed stimuli. The indices were close to the background values when the light was not displayed and on the background of the 10-Hz stimuli. Increase of the light flashing frequency led to considerable increase of the reproduced interval, i.e., with quickening of the flashing rhythm, and in several cases this rhythm was imposed by the brain biopotentials, the subjects underestimated the time intervals, there was subjective quickening of time passage. In several cases this increase reached 8 - 9 seconds /178
in place of five seconds. For several subjects the reproduced interval decreased with decrease of the frequency, reaching 3 - 4 seconds, i.e., there was subjective slowdown of time passage, as a result of which the time interval was underestimated. The reproduced interval suffered most obviously in the case of the variable imposed stimuli frequency. We note that when the errors were corrected in the course of the experiment the subject reproduced the given time interval more accurately on the following days, while retaining the pattern noted above.

It seems to us that we can conclude from all this that physical fields, including the electromagnetic field, affect in some way the nervous system of animals and man. It is very probable that the electromagnetic field pulsation is associated with the operation of the organism's "biological clock", whose rhythm is associated with the physiological processes. In such cases we cannot ignore the problems which arise when the cosmonauts leave the bounds of the earth's magnetosphere.

Even prior to the manned flights to the moon, we suggested that in view of the fact that stable biological reaction rhythms have been developed in the evolutionary process of terrestrial life these rhythms may be retained in the absence of the earth's electromagnetic field. This was later confirmed. But so far the cosmonauts have left the earth's electromagnetic field only for a few days. Therefore, we must find out how long man can exist in a nonmagnetic medium without disrupting the physiological functions. This is particularly important since marked increase of the mortality in comparison with a control group of animals has been found in experiments on mice exposed repeatedly for long time periods to conditions of reduced geomagnetic field intensity.

In performing interplanetary flights the cosmonauts may also encounter powerful electromagnetic fields whose rhythmicity will differ markedly from the usual terrestrial field. Our experiments showed to some degree that change of the brain's biopotential rhythm by photostimulation alters man's perception of time. In numerous studies, Kholodov established experimentally that electromagnetic fields of quite different frequencies and intensities affect the electrical activity of the brain cortex and the subcortical formations. Therefore, it is not impossible that change of the rhythmic activity of the brain under the influence of electromagnetic fields may lead to significant shifts in man's perception of time, and therefore of his own motions and the motions of his surroundings.

In his visionary novel "The Newest Accelerator", H.G. Wells /179
outlined the pattern of change of his heroes' movements

and their perception of their surroundings in time during marked increase of the rhythmicity of the processes taking place in their bodies. Something similar is actually encountered in the case of certain diseases of the central nervous system, when taking certain pharmacological substances, and under the action of unusual stimuli on man. Characteristic in this regard are the results of observations of Bashkova and Zakhar'yanets of a 12-year-old boy who had never suffered previously from any psychic deviations, but after an attack of malaria developed several unusual disorders in the sensory sphere. All objects appeared considerably smaller in size to the patient. He began to perceive speed incorrectly: everything seemed to him to take place faster (for example, it seemed to him that people ran rather than walked). Therefore, he himself began to do everything very fast. These phenomena disappeared after treatment with quinine.

It is difficult to say at the present time what degree of influence electromagnetic fields with other frequencies and other intensities will have on the cosmonauts and how these influences will be expressed. It may be that the threat of "biological clock" disruption and the onset of corresponding serious disruptions of the psychophysical functions is realistic. Then we will have to find ways and means to protect the cosmonauts from the action of electromagnetic fields.

In the final analysis, it is now becoming more and more clear that a detailed study of the influence of the electromagnetic field and its changes, and also the influence of a nonmagnetic medium on the human organism (and on man's image of the external world), is on the agenda as a logical scientific development.

CHAPTER 4

HUMAN MOTOR ACTIVITY IN OUTER SPACE /180

When performing maneuvers, controlling the operation of the various spacecraft systems, and also carrying out assembly operations in orbit near the earth, on the moon and planets of the solar system, man must operate with control organs and various tools. There is no doubt that the effect of the earth's gravity force had a decisive influence during evolutionary and individual development of man and the animals, not only on the arrangement of the skeletal and muscular apparatus but also on the biomechanical and psychophysiological mechanisms which accomplish the motor acts of the living beings inhabiting our planet.

Even prior to space flights, the foreign scientist Haber considered that the absence of the gravity force would alter sensomotor coordination seriously because of disruption of the interaction between the visual, tactile, and motor analyzers. Armstrong and Gaspe also indicated the possibility of motion coordination disruption, explaining this by the fact that man when performing motions under weightless conditions will develop excessive energy, corresponding to the terrestrial motor stereotype and not corresponding to the new conditions of existence.

This is why the problem of man's motor activity in all its complexity faced the investigators during preparation for the first manned space flights.

MOTION COORDINATION IN WEIGHTLESS CONDITIONS

Foreign investigations of motor coordination under weightless conditions were initiated by Lomonaco et al. in 1956. For his studies Lomonaco constructed a so-called Roman tower 14 m tall. A chair was suspended on elastic links in the bath. The chair was placed in the lowest position and the subject /181 was seated in it. Then the chair was released from the locks, was driven to the top of the tower by the elastic links, and then dropped back down. However, it did not reach the ground but was thrown back upward, but to a lesser height. In the first "flight" a dynamic weightless state lasting 2-3 seconds developed in certain segments of the trajectory.

Similar studies were initiated in the Soviet Union by Gurfinkel, Isakov, and other investigators in 1958 in the high elevator of Moscow State University.

In Lomonaco's experiments the subject was assigned the task of hitting a 15-cm-diameter target with the point of a pencil. In these experiments marked scattering of the hits over the entire target was recorded, but this scatter decreased considerably as the test was repeated under weightless conditions. In the experiments conducted by Gurfinkel, Isakov, and others the subjects also hit a target; however, the accuracy of the hits did not change significantly. Deficiencies of these experiments include the extreme briefness of the weightless state and the alternating accelerations, which made analysis of the data very difficult.

More complete information on the motor coordination changes was obtained by Grossfeld and Ballinger under weightless conditions reproduced in airplanes. In their studies these authors noted that the subjects had difficulty in hitting a target with their hand and in certain cases they missed entirely.

Beck made the experiment somewhat more complex. Under weightless conditions the subject with eyes closed and open was assigned the task of drawing crosses in special squares along a downward diagonal. Under level-flight conditions the test was performed quite satisfactorily. However, under weightless conditions with the eyes closed in most cases the crosses began to deviate after the third cross at a 90° angle from the diagonal toward the upper right corner (Figure 15). Approximately the same results were obtained by Gerathewol in studying the accuracy of hitting a target with a pencil (Figure 16). In the weightless state the subjects hit about 1 cm above and to the right of the target. The investigators noted that the motion discoordination was more marked in the beginning of the weightless period.

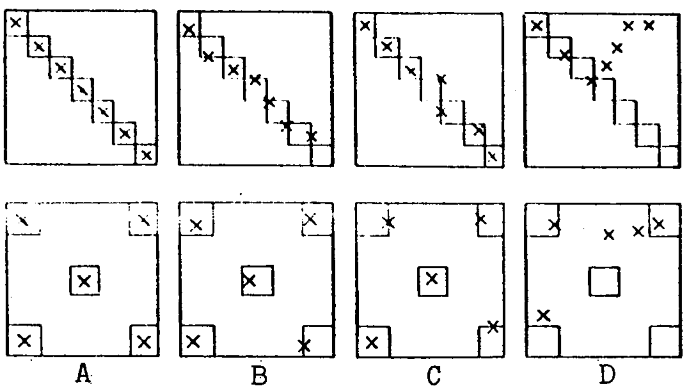


Figure 15. Motion coordination task performance under weightless conditions (task is to make cross in the square).

A - Performance of task under normal conditions with eyes open; B - same with eyes closed; C - weightless conditions with eyes open; D - same with eyes closed.

Kitayev-Smyk studied motion coordination under brief weightlessness with the aid of writing tests and target shooting. It was found that under weightless conditions the shooting accuracy decreases — a typical error is observed: shifting of the hits upward and to the right. Together with Zverev he found that in this case motion time required for activating toggle switches increases. The number of errors in setting indicator pointers to a given position increased by about three /182 to four times in comparison with the basic values.

The motion coordination disruption mechanism in the first simulated weightless flights was explained as follows. On the earth, when an individual lifts his arm or leg he overcomes with the aid of muscle effort not only the inertia of the limb's mass but also its weight. However, under weightless conditions, when weight "disappears," only a small muscular effort is required to overcome the inertia of the limb. Yet in accordance with the habits developed on earth the "nerve centers" send stronger pulses to the muscles in the beginning of the motion, as a result of which an "overshoot" occurs. Specifically, the arm of an individual striking a target shifts upward.

The study of motor coordination in short-term weightlessness was made using a special instrument — a coordinograph. Experiments were conducted on the ground, in level flight, and in flight along the Keplerian curve. These studies showed that for some of the cosmonauts the rate of performing motor acts slows down under weightless conditions. For example, in his experiment Popovich noted: "When performing the exercise on the coordinograph it is very easy to hit the socket provided the movement is made smoothly. In the case of abrupt movements there are misses and the body alters its position." In subsequent flights the rate of performance of this test was the same as under ground conditions.

A similar pattern was noted in analyzing several motions made in performing working operations to orient the spacecraft in Komarov's case. During the second orbit he spent about twice the time on movements concerned with orientation of the ship as he did in the later orbits or in the spacecraft simulator. The same situation was noted by Yegorov when performing nearly all the medical manipulations. It is not impossible that nervous and emotional tension, along with the physical effect of weightlessness, may affect the coordination structure in the beginning of the flight. Specifically, this is indicated by the report of Popovich, who emphasized that the novelty of the sensation in weightless conditions causes some tension when performing work. /183

It is very important when working with the control organs and other spacecraft systems to retain stable skills in reproducing definite muscular forces. During the weightless flights it was found that this involves definite difficulties. Thus, in one of the experiments the cosmonauts had developed a stable skill in reproducing a given muscular force of 750 g (to within 1 g). According to the reports of the subjects, they did not feel any difference in overcoming the corresponding resistance of the dysometer lever on the earth and under weightless conditions. However, the movie film showed objectively that work accuracy decreased markedly in weightlessness. In their first flight the cosmonauts exceeded the given force by 250 - 1125 g. Only for Bykovskiy did the difference between the forces created on the ground and under weightless conditions remain the same to within about 50 g. The error amplitude gradually decreased with increase of the number of flights and continued correction. As a rule the subjects maintained the given muscle force quite stably by the second to fifth flights.

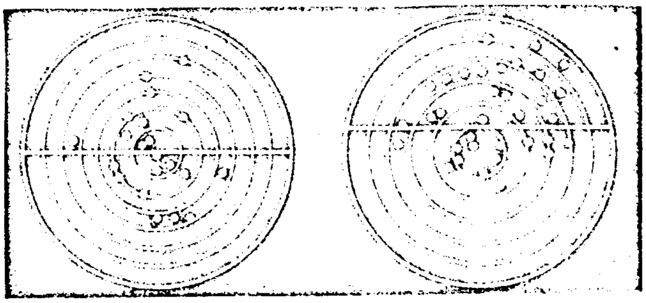


Figure 16. Results of stylus hits on target in level flight (left) and under weightless conditions (right)

These deviations in the reproduction of a given muscle effort are a consequence of the fact that the individual does not expend effort on performing static work in holding back his hand under weightless conditions; therefore, the magnitude of a given dynamic effort increases by a factor of 1.5-2 in comparison with the reference values. /184

In this regard the studies made by Voskresenskiy, Kas'yan, and Maksimov during the flight of the Voskhod spacecraft are of interest. The flight plan for this ship provided for a test with a dynamograph which involved performing a series of rapid rhythmic squeezes of the dynamometer with the hand, using a force of 3-5 kg during a period of one minute. The skill in performing this task was developed by the cosmonauts during the period of preparation for the flight. After the flight was over the dynamogram recordings were compared with the ground results. In the analysis the force (amplitude), duration, and rhythmicity of the dynamometer squeezes were evaluated.

Yegorov worked with the dynamometer for 43 seconds during the second flight orbit. The dynamogram showed marked shifts in the rhythm and dynamics of the dynamometer squeeze forces. The operation was initiated with an accelerated rhythm, but then the squeeze frequency decreased to the values recorded on the ground. At the same time there was a progressive decrease of the squeeze force and duration.

The variations of the dynamometer readings for Yegorov on the ground (1) and during flight (2) are shown in Figure 17.

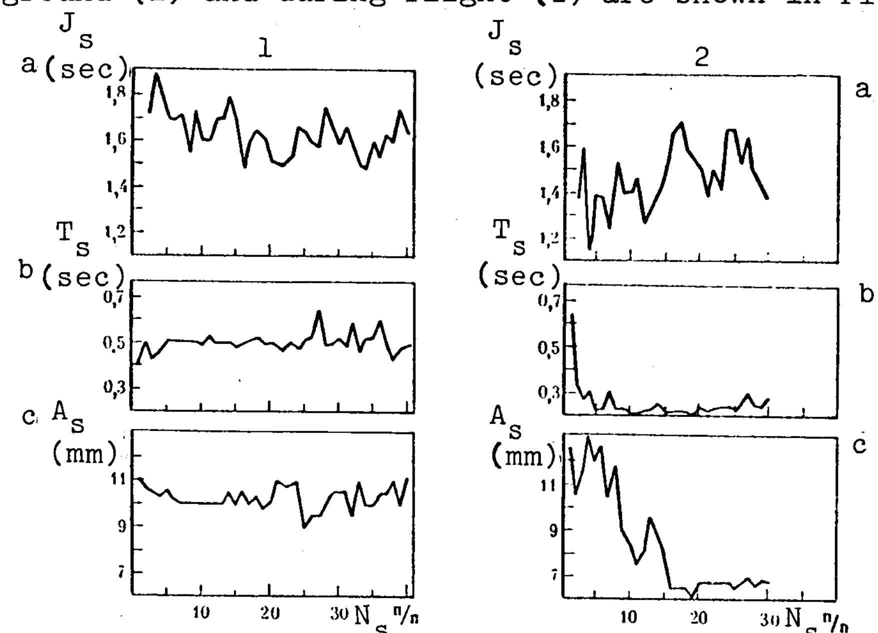


Figure 17. Dynamometer recordings for Yegorov on the ground (1) and in flight (2). Marks on abscissa axis correspond to successive dynamometer squeezes. Ordinate axes are: a) cycle duration (J_s, sec); b) dynamometer squeeze duration (T_s,sec); c) squeeze amplitude (A_s,mm)

Feoktistov performed the dynamograph test during the fifth flight orbit. Analysis of the dynamogram also showed some disruptions of the cosmonaut's motor coordination skills under the extended weightless conditions. Komarov performed the test for a period of 62 seconds at the end of his flight (13th orbit). Comparison of the dynamograms which he recorded on the ground and in flight showed some differences, which are also associated with the coordination change when reproducing a given muscular effort under flight conditions.

Thanks to the special training sessions on the ground and in the "weightless pool," the cosmonauts adapted quickly to the "disappearance" of weight in the orbital flights. For example, while performing the first space flight Gagarin carried on radio conversations, wrote in the log book, turned switches on and off, and made observations. During these operations he did not note any motion coordination disruption although he did feel some discomfort because of absence of the customary pressure of the back and seat of the chair on his body when performing any particular working operation. /185

From flight to flight the cosmonaut activity became more and more extensive. They observed the stars, polar aurorae, satellites, the earth's surface, measured star altitudes above the visible horizon, checked the stability of a gas bubble in a liquid and a water bubble in a gaseous medium, took movies, oriented and docked the spacecraft, and so on. The cosmonauts reported that the usual working operations (throwing switches, spacecraft orientation and docking, work with the telegraph key, and so on) were performed easily and with an adequate degree of coordination. However, Feoktistov noted that active correction of the forces in the process of goal-directed activity, the necessity for retaining the required body position in relation to the surrounding instruments, objects, and so on quite quickly led to a feeling of fatigue.

Analysis of the objective data confirms the pattern outlined in the cosmonauts' reports. In examining the movie films no gross changes of sequence in the coordination of large-amplitude motions were observed. Manual orientation and docking of the spacecraft were performed in complete accordance with the flight plan.

The cosmonauts will encounter a weight change when landing on the lunar surface. A man weighing 70 kg will weigh only 11.6 kg on the moon's surface. Since his muscle force remains /186 unchanged, the rate and nature of the motions change considerably in comparison with those developed on the ground. Long before the flights to the moon Tsiolkovskiy wrote of the impressions which people would experience on our natural satellite: "Rocks tossed upward will rise six times higher than on the earth and will fall back so slowly that one will tire of waiting." "I feel like I'm standing so easily, as if I were up to my neck in water; my feet scarcely touch the floor... I can't withstand the temptation — I take a jump... It seemed to me that I rose quite slowly and came back down just as slowly" (1960, pp. 7-8, 211).

Prior to preparation for the cosmonauts' flight to the moon, the question was posed of whether they could actually coordinate their movements in their first steps in the changed gravity as well as Tsiolkovskiy had imagined.

For example, studies made by foreign scientists on a special stand showed that a slow walk performed while simulating the reduced ("lunar") gravity is accomplished without any special difficulty. However, fast movements lead to loss of equilibrium. Sometimes the subjects fell. At the same time they were able to perform exercises which only experienced gymnasts could do on the earth. To illustrate the sensations which arise in such training sessions we cite the conversation of one of the subjects: "The first step. No doubt I put too much effort into it. I float up with amazing ease and, moving my legs helplessly, I come down several meters from the "takeoff." But not where I intended to be at all. Another push and it all happens again... I try to run without any luck. I push off sharply and energetically with my feet and... fall. It feels like a sudden fall on the ice; the faster I try to move my legs the more difficult it is to keep my balance... I try to move about using short steps, somewhat sideways. It's easier to keep my balance this way. It's very strange but the speed of a pedestrian on the moon will probably not exceed 1.5 meters per hour — 20 steps a minute. And all this simply because when one pushes off from the lunar surface he will come back down more slowly than on the earth. Once again I try to jump up on a "lunar rock" (this is what the subject imagined the low bench to be — the authors). I managed to plant one foot on the rock, but only one. I tumble across the obstacle and come to a stop a meter away, beyond it. And not immediately, but after hovering for some time in the air in a very intricate pose."

It is obvious that when simulating lunar gravity the movements are limited by the simulator and this distorts the observed pattern. A "cleaner" reduction of the gravity force can be obtained in airplanes when performing specially designed maneuvers.

The simulators and airplane flights permit the cosmonauts /187
to prepare for movement on the lunar surface.

The astronauts' observation of their locomotion when stepping out onto the moon is of interest.

As he stepped out onto the lunar surface and took his first step, Armstrong said: "That's one small step for man — one giant leap for mankind." On the television screens his movements were reminiscent of those of a diver at the bottom of the sea. He transmitted over the radio: "...no difficulty in moving aroung...it's even perhaps easier...than the simulations on the ground."

He could be seen exiting from the module. He turned slowly through 360° and waved his hand in the direction of the television camera.

Then he began to take lunar rock samples using a special shovel and packed them in a small cellophane bag, which he then placed in a pocket of the space suit. His movements became more confident and faster. Then he moved still further from the lunar module and disappeared from the camera field of view.

Suddenly he appeared on the screen running over the lunar surface. He was running but not the way we run on the earth. His gait was reminiscent of a man running in a movie taken in slow motion. He took still another small bag for soil samples from the storage hatch and again disappeared from the camera field of view.

Then Aldrin appeared from the module hatch. He came down more confidently than his predecessor. Aldrin jumped the last two steps of the ladder.

The astronauts worked for several hours on the lunar surface. Man's sortie onto the lunar surface showed that although the coordinative structure of his movements changes somewhat, this structure provides quite well for performing locomotion and working operations.

But how about more delicate motor coordination? We have already mentioned its disruption when performing the dynamographic tests. The qualitative and structural changes in radiotelegraph communication skill, which is a delicate form of coordinative motor activity, are also informative in this regard.

In teaching radiotelegraphy the instructor usually tries to get the pupil to develop a smooth radio operator's "fist," which is characterized by standard dimensions of the individual elements of the Morse alphabet symbols.

Studies made by Ivanov, Popov, and Khachaturyanets showed that this skill becomes disorganized in the beginning of space flight: the pause between the symbol elements doubles, the dash becomes somewhat longer, and so on. A study made 6-7 hours after initiation of the flight showed that the average length of the dots and the space between the symbol elements is restored. However, the entire symbol is transmitted in somewhat compressed form, while a more complex action than /188 the dot impact on the key, such as the transmission of a dash, is still too long.

One of the most delicate displays of voluntary movement coordination is the writing skill, whose stability is expressed externally in a handwriting which is characteristic for every writer. Mantsvetova, Neumyvakin and others studied handwriting changes during flight for cosmonauts Titov, Nikolayev, Popovich, Bykovskiy, and Tereshkova. In these studies it was found that the cosmonauts' customary writing motion coordination changes during orbital flight. This showed up in differences in the shape of the same letters and their elements, in unevenness of the lines, and in nonuniformity of the hand movement when writing. Such handwriting changes are characteristic precisely in the case of insufficient coordination of the large movements, which are performed primarily by the upper arm, the forearm and the entire hand, with the small movements of the hand and fingers. Moreover, in the entries made by the cosmonauts in the flight logs we observed breaks and waviness of the lines, angularity of the oval and arc-shaped elements of the letters, and a general lack of orderliness. Such facts are indicative of decreased precision of the fine movements.

The largest changes were noted in the beginning of the orbital flight. The motor coordination improved in the second to seventh orbits.

The handwriting changes during the first two orbits indicate difficulty in coordinating the delicate movements which provide for smooth transition from the flexor elements to the extensor elements. The largest disruptions were noted in the arc-like movements, which require smooth transition from one direction of motion to the other. While under ordinary conditions such movements are performed by a complex combination of flexor-extensor and adducting-abducting movements of the hand and fingers, under weightless conditions simplifications appear and the flexor-extensor or the abductor-adductor motions begin to dominate. As the flight continues, adaptation of the coordination to the new conditions takes place. At the same time, signs indicative of the formation of new coordinative relationships appear in the handwriting of the cosmonauts. In the course of the flight there is an increasing tendency toward simplification of the movements, their interaction also becomes simpler, as does the structure of the letters. Moreover, there is an increase of the pencil pressure on the paper and the number of connecting lines. The written symbols which are made separately under normal conditions are connected with fine, hardly noticeable lines when written under weightless conditions (the last letter in a word is connected with the following comma, and so on).

According to the data of Volynkin, Akulinichev, et al., analysis of Yegorov's handwriting during orbital flight showed a 51% increase of the time for making double spirals with the eyes open and an average of 17% with the eyes closed, and there was also disruption of the movement rate stereotype /189
when making individual elements of the spirals. It is of interest that the number of motion stereotype disruptions with the eyes open is greater than with the eyes closed. Thus, while in flight the number of errors with the eyes open was in a ratio of 7:1 to the figure under ground conditions, the ratio was 5:3 with the eyes closed.

For Yegorov the motor skill in writing the figure 6 and drawing a pattern changed less in flight than the skill in making the double spiral. The time for writing the figure 6 with the eyes both open and closed increased by 11-12% in flight, while the time for drawing a pattern with the eyes open increased by 9%. The reason for the smaller disruption of the motor skills in writing the figure 6 and drawing the pattern is obviously the relatively greater stability of these skills (reinforced skill) in comparison with the skill in making the double spiral, which was acquired prior to flight.

Thus, in orbital flight the delicate motion coordination (in writing, for example) changes significantly. Here the importance of the force component becomes different and the customary interactions between the central and peripheral sections of the motor apparatus are disrupted. Extended exposure to weightlessness is accompanied by corresponding adaption, expressed basically in simplification of the movements. Such adaption is noted in the first few days and intensifies in the course of the last days of the space flight.

We see from this data on motion coordination study in weightlessness that the investigators paid particular attention to the external pattern of the actions performed, the individual motion parameters, and the final result of the actions. However, the internal structure of the movements, which permits study of the intimate mechanisms of rearrangement and control of the movement structure under qualitatively new ambient medium conditions, were not investigated. Chkhaidze made an attempt to analyze the movement control mechanism under the influence of positive load factors on the basis of changes of the leading dynamic components of the force differentiation motor skill. However, he did not investigate the motion organization of the multielement kinematic chains, which are associated with significant displacements of the latter in space.

In this connection we studied the internal coordination structure of man's voluntary arm movements under conditions of alternating action of positive load factors and weightlessness during flight of a flying-laboratory airplane along a Keplerian parabola. Experiments were also conducted in water. The latter were made because of the fact that the question of /190 the best way to utilize the water medium for simulation of the professional and working activity of the cosmonauts under weightless conditions was still an open question.

Under the direction of one of the present authors and Chkhaidze, research assistant I.F. Chekirda used the subject, "The Coordination Structure of Man's Voluntary Arm Movements Under Conditions of Brief Weightlessness, Positive Load Factors, and in a Water Medium," for a dissertation project and published several papers.

In the following section we shall present data on movement coordination structure under weightless and positive-g conditions, since these conditions are typical for space flight.

BIOMECHANICS OF HUMAN MOVEMENTS UNDER ALTERED GRAVITY CONDITIONS*

In the preceding section we noted that some disruption of movement coordination took place in the first flights in airplanes simulating weightlessness, that these disruptions are short-lived, and that the individual adapts quickly to performing movements under unusual conditions. However, as a result of what changes in motion coordination structure is motor skill coordination recovered under conditions of weightlessness and positive-g? Or are these changes temporary and, as

*This section was written together with I. F. Chekirda.

adaptation to the unusual conditions develops, does the motion structure begin to be accomplished just like it is on the ground? In order to answer these questions we must find a technique which will not only permit establishing the time pattern of the actions under study or their individual parameters, or the final result of the action, but will also yield the possibility of understanding the "mechanism" of these actions. In other words, it is necessary to study the microstructure of voluntary human movements under conditions of weightlessness and positive-g. Under the action of earth gravity (hereafter we term this conventional gravity), this problem has been solved with the aid of various methods, among which cyclography plays the primary role.

The first experiments in creating weightlessness were made in 1965 together with Chkhaidze and Kolosov in flights of a flying-laboratory airplane along a Keplerian parabola. We studied the structure of the following arm motions in the elbow joint: slow flexion and slow extension of the unloaded arm; slow flexion and extension of the loaded arm (3-kg dumbbell); fast flexion (jerking) and fast extension (striking); fast aimed extension (striking a target with the finger). /191

In later investigations Chekirda studied: fast flexion and slow aimed extension of the unloaded arm, performed with and without elbow fixation by a restraint system to the table surface; slow flexion and fast aimed extension of the unloaded arm, performed with and without elbow fixation; slow flexion (waving) and fast aimed extension (striking) of the loaded arm (0.8-kg hammer), with and without elbow fixation.

The studies were conducted in a blacked-out airplane cabin. The subject was restrained to the seat in the waist and pelvic area in order to maintain the same posture during airplane maneuvers. The arm movements were recorded using a 16-mm camera so that the plane of motion was parallel to the plane of the photographic film. A shutter with four slits was mounted in front of the camera and driven by an electric motor at 16 rps. This gave a cycloframe frequency of 64 positions per second.

Miniature electric bulbs were attached to the right arm of the subject at the projection of the centre of gravity of the hammer (when used) and the hand (main phalanx of the second finger), and also on the horizontal axes of the radio-carpal, ulnar, and shoulder joints. As a result of this photography we filmed broken trajectories of the motion of identifying points of the arm's kinematic chain elements.

We shall discuss briefly the technique for analyzing the resulting cyclograms. We first exposed on photographic paper a half-millimeter grid and then the cyclogram negative to the selected scale. On the resulting photographic projection lines were drawn from the arm with the distance marked in full-scale millimeters. After this we can read off the concrete coordinates of each point of the cyclogram trajectory along the horizontal and vertical. After measuring the coordinates of all the trajectory points, we calculate the velocity components. The difference in the value of the coordinates of neighboring points, referred to the corresponging time interval between them, is the average velocity at the mid-point of this trajectory segment. The difference in the values of the first differences, referred to the same time interval, is the average acceleration.

Multiplying the resulting acceleration at the center of gravity of the member by its mass, we obtain the force. The optimum interval for determining the velocity and acceleration components is considered to be about 0.05 second (N. A. Bernshteyn). For the cycloframe frequency used of 64 positions per second this corresponds to four sequential intervals between points.

In this case the velocity at the n-th point is /192

$$V^{n} = \Delta'^{(n+2)}_{(n-2)} \cdot \frac{\nu \cdot \alpha}{\beta} \text{ mm/sec.}$$

where Δ' is the difference between (n+2) and (n-2); ν is the cycloframe frequency; α is the ratio of the full-scale magnitude to the photographic projection scale; β is the number of intervals over which the calculation of the first difference is made.

The acceleration at the same point is

$$W^{n} = \Delta''^{(n+2)}_{(n-2)} \cdot \frac{\nu^2 \cdot \alpha}{\beta^2} \text{ mm/sec}^2.$$

The force components are found from the formula $F_{gmg} = W \cdot P_m / 9810$ kg, where P_m is the member weight, 9810 is the gravity force acceleration in millimeters.

We analyzed the resulting data using parametric graphs of the horizontal and vertical components of the velocities, accelerations and forces. In certain cases we plotted graphs of the overall muscle moments, joint angles, and sequential positions of the members with the vector forces at the most important motion times.

The study of the coordination structure of voluntary human arm movements in weightless conditions and with positive load factors acting was performed from flight to flight on 19 subjects, three of whom (Nikolayev, Komarov, and Bykovskiy) had spaceflight experience. In all we obtained 812 cyclograms, which we used to analyze the performance of actions under different gravity force conditions. Of this number 118 cyclograms were analyzed using parametric graphs of the velocities, accelerations, forces, and over-all muscle moments.

BIOMECHANICS OF VOLUNTARY HUMAN ARM MOVEMENTS UNDER CONDITIONS OF NORMAL GRAVITY FORCE ACTION

We shall first describe in very general form the principles of motion control. The higher coordination centers of the central nervous system control motion by sending impulses to the motor apparatus. These impulses reach the periphery, where they cause motion or alter a motion which has already been initiated in accordance with its objective. The resulting changes are perceived by the peripheral receptor field, are coded and transmitted along the nerve conductors to the higher coordination centers, signalling the phenomena taking place at the periphery. The coordination centers receive and process the information entering the brain, take account of the general progress of the motion, and if necessary alter their effector /193
impulses.

The idea of cyclicity in the interaction of the motion with the surrounding medium was proposed by Bernshteyn in 1935. He identifies peripheral and central interaction cycles. In the peripheral interaction cycle the muscle tension causing the motion alters the distance between the muscle fixation points, and this affects the degree of muscle tension. In the central nervous system there exists a central governing interaction cycle, in which the motor impulses are generated and then travel to the periphery and cause motion; the information from the periphery, in turn, modifies the motor impulses formed in this center.

In the parametric graphs of the accelerations, forces, and overall muscle moments this process is reflected in the appearance of characteristic wave discontinuities. In 1940 Bernshteyn on the basis of study of human locomotor acts established three categories of discontinuities:

— spontaneous innervation waves of central origin, which reflect directly the effector impulses arriving at the periphery;

— reactive waves of peripheral origin, which arise upon interaction of the reactive forces during displacement of the limb kinematic chain members;

— reactive innervation waves of mixed origin, which reflect interaction of the direct nerve impulses with the play of the reactive forces at the periphery.

In accordance with this classification Chkhaidze divided the dynamic components of the motion coordination structure into primary or guiding, associated, and secondary.

According to Bernshteyn, the basic characteristic of the waves of spontaneous innervation origin is their presence in the force component curves for the centers of gravity of all the members in like form, while the characteristic feature of the waves of reactive origin is their presence in the force curves of neighboring members simultaneously but with opposite direction of the peaks.

According to Bernshteyn, in each motion we must differentiate the motor task (conceptual aspect of the actions) and the motor composition of the action, which depends on the kinetic capabilities of the organism and is determined by the arrangement of the body's kinematic chains, the innervational resources, the presence of sensory corrections, and the instrument which can be used to perform this action.

Such subdivision of the motions acquires great importance in studying the disruption, formation, and establishment of a /194 motor skill under new gravity conditions, when along with retention of the conceptual orientation of the actions there are disruptions of the motor composition, which lead to discoordination of the movements.

Characteristic of all the motions in question are the general laws governing the coordination structure, which we shall consider using the example of performance of slow movements by cosmonaut Komarov. Figure 18 shows the force variations at the center of gravity of the hand as Komarov performs slow flexion (I) and slow extension (II) in the elbow joint under normal gravity conditions during a flying-laboratory airplane flight.

The requirement to initiate the motion (flexion) causes the appearance on the horizontal and vertical force component curves of the typical discontinuities — the γ and A waves, which reflect directly the activity of the central nervous system in transmitting a starting signal for lifting of the arm. This part of the motion is completely defined by the conceptual motion task. Therefore the γ and A waves should be considered spontaneous innervation waves. The decay of these waves terminates by the appearance of waves with opposite direction of the $n\gamma$ and nA peaks, which are reactive in origin. They reflect the reaction of the periphery to the initiation of the motion (reactive forces).

Then, throughout the first half of the flexion there follow several waves A^1, A^2, and so on in the horizontal and γ^1, γ^2, and so on in the vertical force components. These waves have peak directions analogous with those of the γ and A waves, reflecting the starting effector impulses. With regard to their origin they are reactive innervational since, first, they reflect the reaction of the central nervous system to preceding waves of peripheral origin and, second, they have a correctional nature, correcting the course of the motion in accordance with the programmed norm. These waves ensure biomechanical expediency of the behavior of the given portion of the motion, which is independent of the performance of the conceptual task and is completely defined by the activity of the "inner motion control ring" (Chkhaidze, 1965).

In the second half of the motion (flexion) there takes place a phenomenon which is at first glance "unusual": the overall force vectors applied to the centers of gravity of the corresponding members change their direction to oppose the general course of the motion. This is reflected in the force curves in the appearance of Δ waves in the horizontal component and A^4 waves in the vertical component, which is caused by the

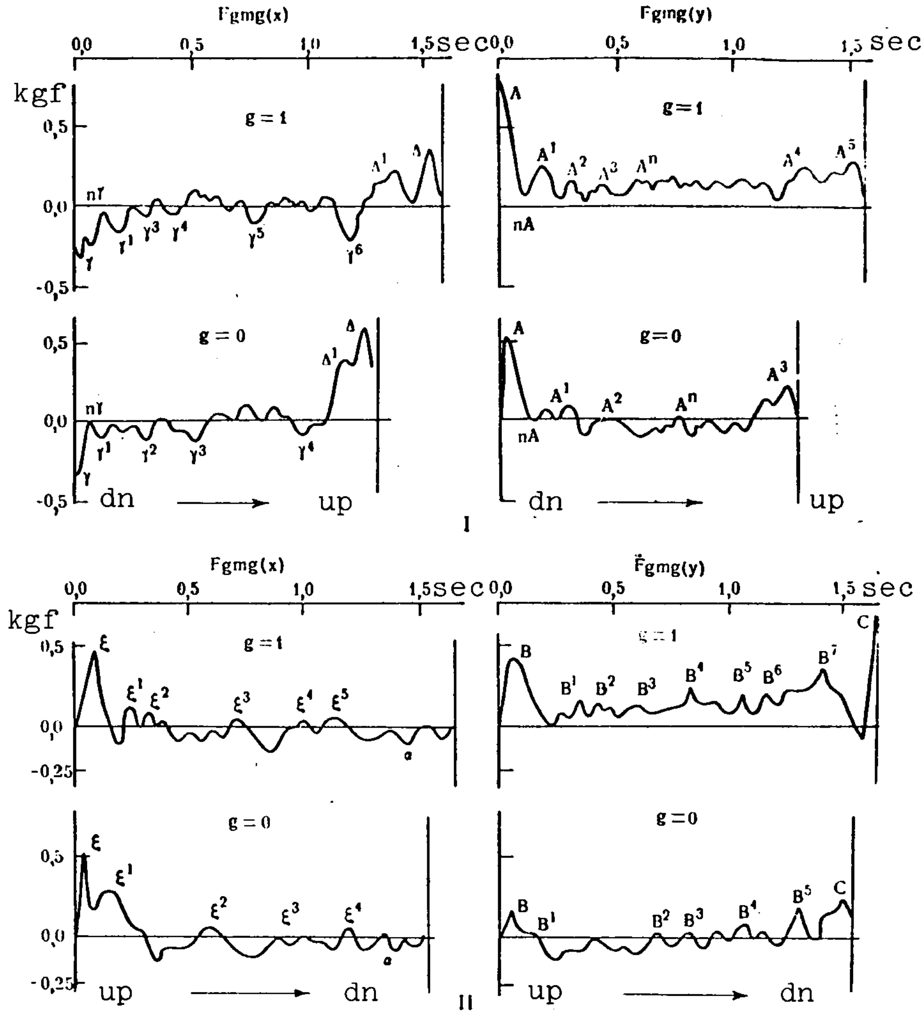


Figure 18. Horizontal (x) and vertical (y) components of the forces (Fg) at the hand center of gravity (mg) when performing slow flexion (I) and slow extension (II) of the unloaded arm under normal and zero gravity conditions during airplane flight along a Keplerian parabola.

necessity for preliminary deceleration of the arm members to absorb the acquired inertia and stop the arm prior to performing the second part of the conceptual task — slow extension of the arm in the elbow joint. Since this task cannot be performed instantaneously, the motion control organs begin to perform this task ahead of time in order to completely attenuate the inertia of the moving system at the required position and at the required moment of time. The central /196 nervous system can begin to perform the extension only after bringing the developed inertial forces to zero. The preliminary deceleration task is completely determined by the higher coordination activity and, therefore, the subject waves are spontaneous innervational. The deceleration waves reach their maximum value at the moment when the moving kinematic system of the arm occupies its highest position.

Additional confirmation of the foregoing was found in the appearance of inhibitory waves when performing flexion under different gravity conditions with and without a load. For example, in the case of motion with a dumbbell the inhibitory waves appeared earlier than without the dumbbell. The magnitude of the gravity force and its direction in relation to the direction of the applied forces plays a role which is similar in significance to that of the load. In the terminal portion of the flexion the inhibitory forces appear earliest under the action of weightlessness, later under the action of the usual gravity force, and still later under the action of supergravity. We find the explanation for this phenomenon in the magnitude and direction of the effective gravity force. It acts opposite the flexion direction and thereby plays the role of an "additional inhibitory force" under normal gravity conditions. Under the action of positive load factors the magnitude of this "force" essentially increases by a factor of two. Under weightless conditions the absence of the gravity force action leads to the necessity for replacing its role by earlier initiation of inhibition. This dependence obviously changes its direction when performing extension.

After reaching their maximum value at the end of flexion, in the beginning of extension the inhibitory forces transform into a second spontaneous innervational wave, causing an active forward and upward thrust of the arm. In the horizontal force component this corresponds to the ε wave and in the vertical component to the B wave. Then again, just as in the first half of flexion, there appear waves of peripheral origin ($n\gamma$ in the horizontal and nA in the vertical force components). In the process of performing the extension there follow $\varepsilon^1, \varepsilon^2$ waves in the X component and B^1, B^2 and so on in the Y component. According to Chkhaidze, these waves are correctional signals of the inner ring, which tracks the course of the performance of the motion. The requirement for termination of the motion with complete cancellation of the accumulated inertia causes reversal of the applied forces shortly before termination of the extension. On the force curves this shows up as waves of spontaneous innervation origin (α in the horizontal and C in the vertical components).

Analysis of the time development of the dynamic waves shows that the solution of the conceptual motion task is not achieved by smooth increase and decrease of the magnitude of a single force but rather by intermittent impulses of definite rhythmicity. The average rhythm frequency is 8-16 Hz. /197
This discreteness in the transmission of corrections is maintained in the construction of all the motions studied and does not change under weightless conditions or under the action of positive load factors.

The curves of the horizontal and vertical velocity components are also of the same type when performing different motions. In the slow motions, after the velocity picks up, a flat plateau usually develops, slightly wavy, which reflects indirectly the correction signals. This plateau is the more marked, the greater the motion duration. It is usually absent in fast motions. At the end of the motion the necessity for performing deceleration causes smooth decay of the arm member velocity.

The rate of increase and decrease of the velocity can be used to evaluate the nature of the behavior of the central nervous processes (M. I. Vinogradov).

Figure 19 shows cyclograms of the arm motions of cosmonaut Khrunov under different weightless conditions. Let us analyze the characteristics of the motion trajectories under conventional gravity force conditions. The trajectory curves are characterized by spatial closeness during arm raising and lowering, or even complete coincidence of the displacement trajectories of the corresponding joints, smoothness of the curves, absence of small and large discontinuities.

All the motion groups studied had their own peculiarities. Performance of motions with a weight leads to complication of the conceptual motion task. This causes an increase of the number of motion corrections by the central nervous system. This is particularly marked in the force curves of the proximal members, which reflects the increased role of the proximal muscle groups in motion organization. The elbow joint muscles have great power, and are assigned the leading role in creating the kinetic energy content and in performing the

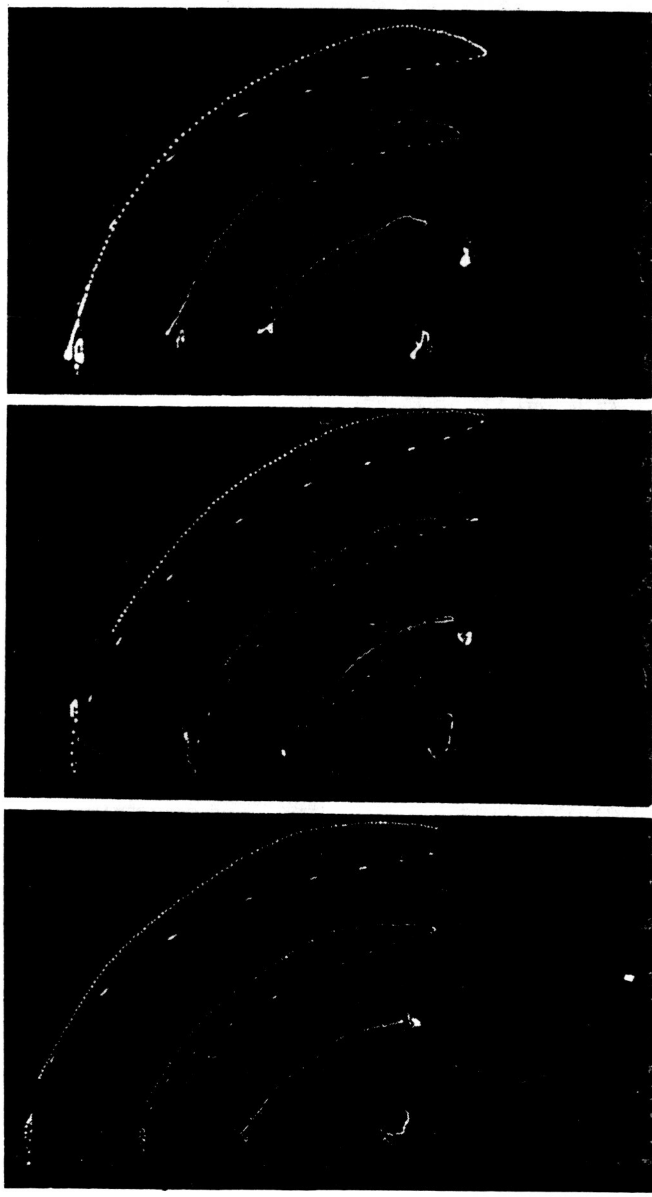


Figure 19. Displacement trajectories of arm and hammer identification points when the subject performs slow flexion (wave) and fast aimed extension (blow) with the loaded arm (0.8 kg hammer) without elbow fixation to a support under conditions of zero, conventional, and 2-g gravity. (In each cyclogram the traces from top to bottom are the displacement trajectories of lamps mounted at the projection of the center of gravity of the hammer, hand, on the horizontal axis of the wrist, shoulder, and elbow joints.)

deceleration. The forces of these muscles are transmitted to both the forearm and the hand. This becomes possible thanks to the fixing function of the forearm muscles, which transform the forearm-hand kinematic chain into a single stationary system, restricting sharply the degrees of freedom in the biomechanically inexpedient directions. However, along with the fixing function, the forearm musculature takes an active part in performing the conceptual motion task.

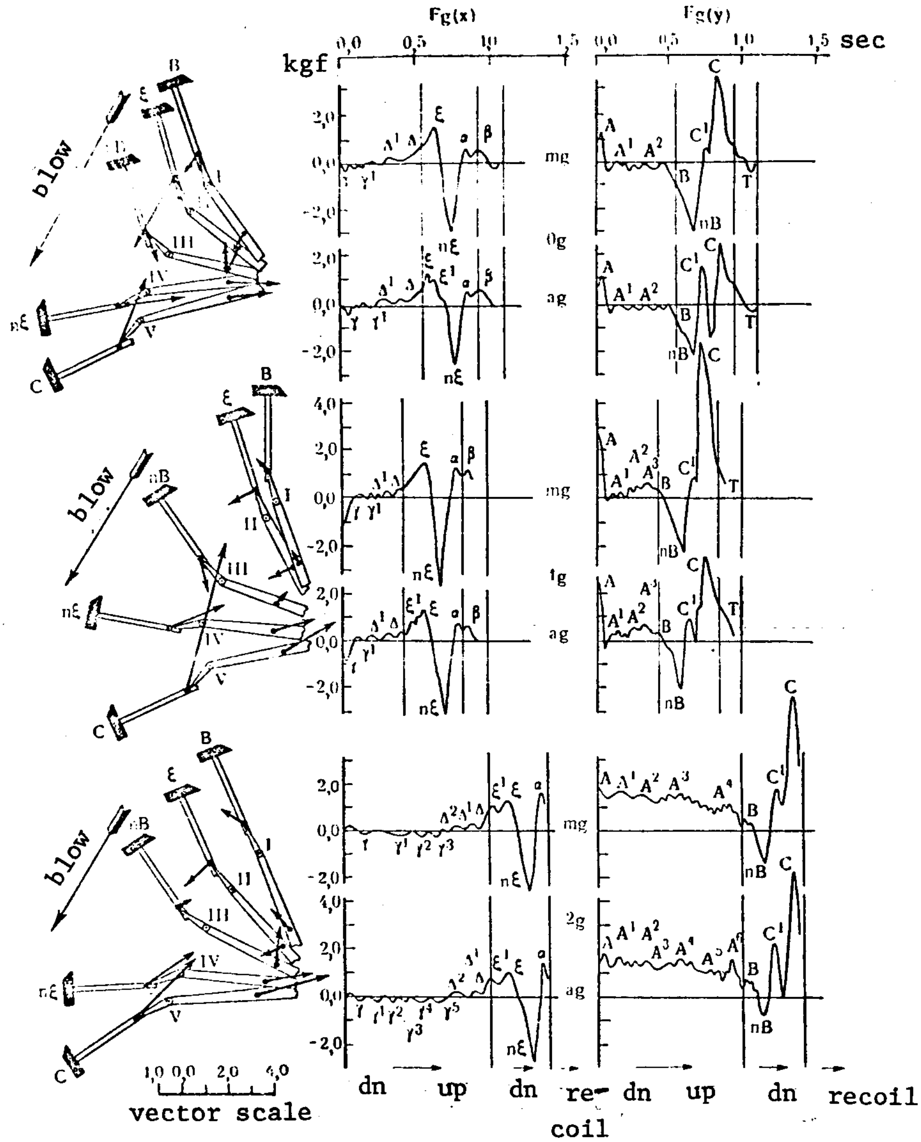
When performing ballistic motions (jerk or blow) the main emphasis is on speed and force. This determines the characteristics of the motion motor composition. The corrections in the course of performing the actions disappear, which is connected, on the one hand, with the time deficit for their introduction and, on the other hand, with their biomechanical inexpediency in connection with the necessity for developing large forces and maintaining a high velocity of the arm members. The initial and final forces take on the primary role, and the /199
conceptual task is performed as a result of these forces. The velocities, accelerations, and forces developed increase by a factor of five or six in comparison with their magnitudes when performing slow motions.

Characteristic of the aimed motions is the clearly marked final targeted stop. In this case the conceptual slow extension task becomes more complicated, including in itself not only the arm lowering task but also that of striking the target with the final member of the arm's kinematic chain. The coordination structure of the motions becomes more complex.

The irregularity of the acceleration and force curves becomes more marked. There is a definite concentration of the correctional signals in the final part of the extension, since the slow performance of the motions makes it possible to introduce corrections in the immediate vicinity of their target.

The conceptual task of fast aimed striking is similar. However, the conditions for introducing the corrections deteriorate in connection with the rapidity of the action being performed. Therefore, absence of the many small discontinuities in the force curves is typical for fast aimed striking, as it is for abrupt extension. Worthy of note is the reduction of the arm member velocities. Motion corrections appear, and most frequently they accompany the primary initial force. When performing flexion the corrections would have been premature, while the transmission of corrections at the end of the aimed blow would also be unjustified because of the rapidity of the completion of the action. The accelerations and forces developed also decrease in comparison with unaimed striking. This is particularly important in the initial portion of the extension, when correctional adjustments are introduced.

The coordinational structure becomes even more complicated when performing fast aimed striking with an object (0.8 kg hammer), which is a result of the complexity of the working motor skill conceptual task (Figure 20). While, in motions without an



/200

Figure 20. Horizontal (x) and vertical (y) components of the forces (Fg) at the center of gravity of the hand (mg) and forearm (ag) when raising a hammer and striking a blow on a target without elbow fixation to a support, and vector curves of the forces together with sequential positions of the arm members while striking under conditions of zero, conventional, and 2-g gravity.

object, a large number of discontinuities were observed in the distal member (fingers and hand) force curves, for the ballistic and semiballistic motions such a role distribution would be excessive for the task. In the slow movements, the powerful muscle groups of the proximal members ensure the construction of the motion "skeleton," while the fine and precise operation of the distal member muscles introduces the required corrections to ensure accuracy of the performance of the final aiming task (striking the target). When working /201 with the hammer, the necessity for accumulating a large kinetic energy supply for the blow determines the leading role of the proximal muscle groups, while the distal member muscles perform basically a fixing function. While losing somewhat in precision in this connection, these motions gain considerably in force, which makes it possible to perform the posed work task. It is interesting to note that, while the primary waves in the force curves increased from the proximal members to the distal members, the waves reflecting the corrections reached their maximum value in the force curves for the centers of gravity of the proximal members.

In conclusion we shall analyze the resulting curves of the muscle moments of the forearm and hand with hammer relative to the elbow joint for subject L (Figure 21, center curve). We recall that a positive value of the muscle moments indicates dominant active work of the flexor muscles, while /202 a negative value of the muscle moments indicates dominant work of the extensors in the elbow joint. The beginning of the raising movement is characterized by work of the elbow flexor muscles in lifting the forearm and hand with the hammer. Thereafter the muscle moment curve crosses the zero line,

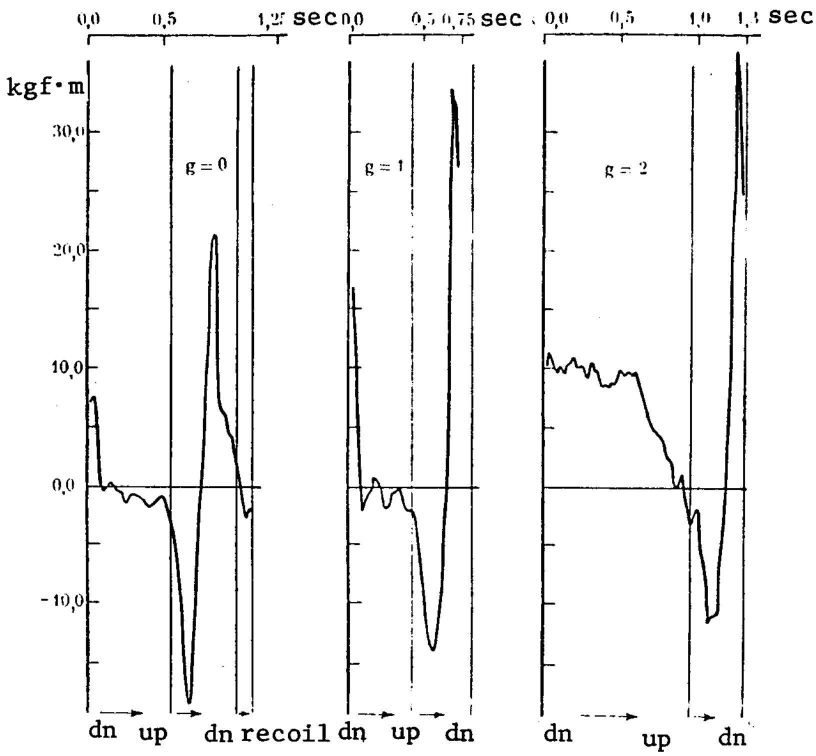


Figure 21. Overall muscle moments of hand with hammer and forearm relative to the elbow joint when raising a hammer striking a target without elbow fixation to a support under conditions of zero, conventional, and 2-g gravity.

taking on a negative value. This reflects the initial retardation of the arm's kinematic chain, performed by the elbow extensors. The accumulation of striking kinetic energy is accomplished by the extensors. At the end of the blow the necessity for converting the mobile kinematic chain into a rigid system for most effective transmission of the accumulated energy to the object on which the blow is being struck leads to activation of the flexors. Thus, the nature of the muscle operation depends on the task being performed and the motion phase. While during the backswing the flexors perform work in accumulating kinetic energy, in the striking part of the motion they perform retardation.

We shall also note the role of the gravity force vector direction. In spite of the necessity for accumulating maximum kinetic energy in the striking part of the motion (12 kgf·m), during the backswing the applied efforts are greater (17 kgf·m). The relationships change when performing retardation. Here the work expended is greater in the striking part of the motion. This is explained by the relationship between the direction of the applied efforts and the gravity force vector. The gravity force action hinders the solution of the posed problem when accumulating kinetic energy in the backswing and during retardation in the striking part of the motion, since the direction of the efforts does not coincide with the gravity force direction. However, during retardation in the backswing and when accumulating energy in the striking motion the action of the gravity force coincides with the direction of the applied muscle efforts, which reduces the work expended.

The curve patterns remained the same with the elbow fixed. There was some simplification of the motion structure, which is explained by the reduction of the number of degrees of freedom of the arm's kinematic chain and, therefore, facilitation of the conditions for performing the actions.

BIOMECHANICS OF VOLUNTARY HUMAN ARM MOVEMENTS UNDER BRIEF WEIGHTLESS CONDITIONS

The general principles of motion structure remain the same under conditions of short-term weightlessness (primary waves which determine the motion morphology are present, discreteness in the transmission of the correctional signals and their rhythmicity). However, the qualitatively new conditions of the ambient medium introduce into the motion coordinational structure significant differences, which are most clearly examined in subjects with considerable weightless flight experience, when the transient phenomena associated with the process of adaptation to the new and unusual conditions are not superimposed on the motion structure. Instructive in this regard are the slow flexion and extension performed by cosmonaut Komarov, who had experience in exposure not only to short-term weightlessness but also to long-term weightlessness during the Voskhod spacecraft flight. /203

The greatest differences in the graph of the motions which he performed are seen in the vertical force components. The amplitude of the A wave decreases by 30% in weightlessness, while that of the A^1 wave decreases by 80%. Several waves are missing. Thus, there is no A^3 wave. And the peak of the A^2 wave is located on the zero line, while under the action of the conventional gravity force its magnitude corresponds to a force of 0.22 kg. Similar changes take place when performing slow extension. The amplitude of the B wave decreases by 52%, while that of the B^1 wave decreases by 75%. The B^2 wave reaches its peak prior to the zero line, while under conventional gravity its magnitude indicated a force of 0.15 kg.

Detailed analysis of the forces applied at the hand's center of gravity for subjects with considerable weightless flight experience showed that in weightlessness the magnitudes of the forces decrease on the average by 50% (by 30-40% in the horizontal component and 80-85% in the vertical). The larger decrease of the force magnitudes in the vertical component confirms Bernshteyn's hypothesis that the competition between the motion and the gravity force is reflected in the vertical component.

The horizontal force components of the primary waves decrease in some cases (γ^1), remain unchanged in other cases (γ), and increase in a third group of cases (Δ,Δ^1). We also note a decrease of the number of horizontal component force curve dicontinuities under weightless conditions in comparison with the normal conditions. However, this is less marked than in the vertical component, which is explained by the interaction between the motion and the gravity force. For example, the increase of the inhibiting waves in the horizontal component under weightless conditions depends on the fact that the absence of gravity leads to the necessity to compensate somehow for its positive role in this case.

Hereafter we shall denote such a process, showing up in the force curves, as reduction or increase of the role of the vertical force components in relation to the horizontal components (assuming that the central nervous system yields integrated corrections, which we artificially break down into horizontal and vertical components).

Thus, while for conditions of normal gravity force action some dominance of the vertical component role was characteristic, in the weightless case dominance of the horizontal component role in relation to the vertical is typical in connection with absence of the necessity for considering the gravity effect.

Figure 20 shows the performance of a hammer blow by cosmonaut Khrunov. When examining the overall force vectors (left half of Figure 20), it is not difficult to see that under weightless conditions the basic motion structure patterns remain the same. In the beginning of the motion the force vectors are directed along the motion, while at the end of the /204 motion, when performing the retardation, they are directed opposite the motion. The absence of gravity force action affects both the magnitude of the applied forces and the time of initiation of their action in the different motion phases. Thus, retardation begins earlier when performing extension under normal gravity conditions (see positions III, IV, and V, left half of Figure 20). Fixation of the elbow facilitates the performance of this task.

Thus, after adaptation to weightlessness the motion coordination structure simplifies in comparison with the background as a result of decrease of the number of central nervous system correction signals. The arm member displacement trajectories become smooth and the small and large waves are absent; however, the arm raising and lowering trajectories do not coincide completely.

A similar synclinization of the motor skill coordinational structure is observed in the final stage of adaptation to weightlessness and occurs between the 20-th and 30-th weightless flights in an airplane, which confirms Pavlov's hypothesis on the necessity for sufficiently long repetition of actions for the formation of strong temporal bonds in the brain's cortex.

At one time several investigators suggested on the basis of theoretical arguments the possibility of an overall reduction of mechanical work (W) under weightless conditions, since $W=S\omega$ (where S is the displacement and ω is the weight, which is missing in weightlessness). Our investigations not only confirmed these conclusions, but, what is particularly important, they showed a decrease of the number of secondary motion corrections. This simplification of the motion coordinational structure makes it possible not only to maintain but even increase, under certain conditions (excellent tolerance to the effects of spaceflight factors, adaptation to weightlessness, firm fixation of the body at the working location), the cosmonauts' activity resolution capability under weightless conditions.

It is interesting that Worth and Prescott, studying energy expenditures by subjects walking on a treadmill under conditions simulating reduced gravity, found a decrease of the magnitude of the work performed by the subjects. Thus, when simulating 1/6g the energy expenditures decreased by 32% at a speed of 3.2 km/hr and by 56% at a speed of 5.4 km/hr. In our studies we found a simpler motion structure, not only as a result of the efforts expended, but also as a result of the /205 smaller number of corrections than under earth-gravity conditions.

We emphasize that these conclusions cannot be extrapolated to man's activity in free space, since the conditions of practically no support complicate considerably the motor activity of the cosmonaut (problems arise in maintaining the required attitude under support-free conditions, stabilization of the body while working, combating rotation when moving, and so on).

The data which we analyzed indicate that man's motor skill coordinational structure is altered under weightless conditions. The motion structure does not approach the earth-gravity norm, but undergoes qualitative changes in accordance with the qualitative changes of the external conditions. L.A. Orbeli wrote the following concerning the capability of the central nervous system to reorganize the motion structure.

"Coordination acts are not something constant, fixed, given once and for all, but are rather variable phenomena which are constantly reorganized, giving way to new coordinational forms, in the course of the entire life of the organism, from the moment of its birth or, more precisely, from the moment of reflex activity development" (1949, p. 448).

After analyzing the characteristics of the motion coordination structure for subjects as a function of the number of weightless flights, it was possible to establish sequential stages of motor skill adaptation to the weightless conditions (Chekirda). Figure 22 shows curves of the forces at the hand's center of gravity when Khrunov performed fast flexion and slow aimed extension after an interruption of a year in weightless flights (first and fifth flights). In the first flight there is an increase of the total time for performing the motions. We see on the force curves that they have many more discontinuities, particularly in the vertical component. Very noticeable is the increase of the size of the waves of reactive origin, which in most cases leads to strong central nervous system correctional signals. When performing the flexion the ε and B spontaneous innervation waves decrease markedly in magnitude, and in spite of the rapid completion of this part of the motion the additional correctional signals, the ε^1 and B^1 waves, are clearly seen. While usually the correction waves are considerably smaller in magnitude than the waves which determine the motion morphology, in the first flights the differences between them smooth out (on the one hand, as a result of decrease of the primary wave magnitudes, and on the other hand as a result of increase of the correction wave magnitudes). Also obvious is the considerable increase of the leading

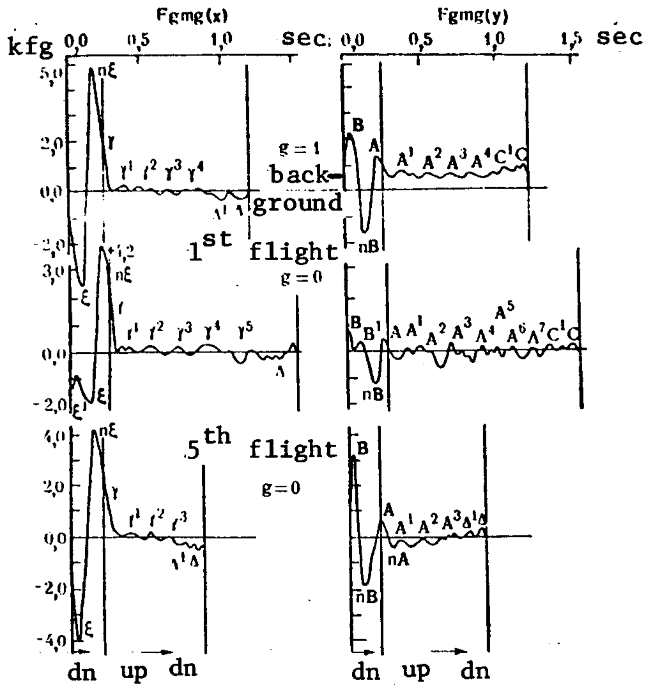


Figure 22. Horizontal (x) and vertical (y) components of the forces (Fg) at the hand's center of gravity (mg) when performing fast flexion and slow aimed extension in the first and fifth weightless flights after a long interruption

role of the vertical force components, where the primary interaction with the gravity force occurs.

We have noted pre- /206
viously that the unusual absence of body weight disrupts both reverse afferentation precision and the compatability in the activity of the analyzers which participate in motion construction. This leads to motion disorganization in the initial period of adaptation to weightlessness, which as we see from the data presented here the central nervous system attempts to eliminate by continuous correction of the course of the performance of the motor skill. The impossibility of controlling the motion structure by the previous methods and the inability to control in a new fashion leads to decrease of the velocity and acceleration extrema, increase of the irregularity of the velocity curves and the arm member displacement trajectories.

Pavlov showed that in the initial period of development of a new skill or adaptation of one's actions to new conditions of the external medium, there is a generalization of the conditioned reflexes as a result of excitation irradiation in the brain cortex. Accordingly, the stage of motion coordination structure complication in the first weightless flights is termed the correction signal generalization stage. /207

By the fourth or fifth weightless flight, the motion structure approaches, with regard to the primary parameters and the number of correction signals, the values typical of conventional gravity. The leading role of the vertical force components decreases to the point of establishment of dynamic equilibrium with the horizontal components. The additional correction waves ε^1, B^1, disappear when performing flexion, and when performing extension the number of corrections decreases by nearly a factor of two in comparison with their number when performing extension in the first flight (see Figure 22, lower part). The wave magnitudes in the horizontal component approach the magnitudes in horizontal flight, while in the vertical component there is further decrease of the wave magnitudes. These phenomena permitted us to term this the concentration or pseudo-stabilization stage, since the adaptation process does not end here and, as shown above, there is subsequent simplification of the motion structure (stablization stage).

It is quite remarkable that T. S. Popov observed similar phenomena when analyzing by the cyclogrammetric method the genesis of the biodynamic structure of walking in children. Walking mastery began with the innervational primitive stage, in which on the force components curves there were only the two primary waves, corresponding to a single pair of reciprocal impulses. The child acquired the necessary set of dynamic walking impulses by the fifth year. Thereafter, walking development took place through the excess dynamic impulse production stage and, finally, there came the stage of final organization of the integral and commensurate form, where the excess waves disappeared.

The absence of the first two stages under weightless conditions is most likely explained by the fact that there was no need for the central nervous system to master qualitatively new categories of motions. The task of the higher coordination centers reduced to simply rearrangement of an already mastered skill, which was subjected to deautomatization and dislodgement.

Let us analyze the characteristics of man's motion structure rearrangement in the case of different complexity of the conceptual task (Chekirda). This analysis became possible as a result of establishing the characteristic motion biomechanics changes in the process of adaptation to the alternating action of supergravity and weightlessness. The motions compared were performed in a single weightless regime. It was found that the rapidity of motor skill rearrangement for a particular subject depends on the complexity of the actions being performed. For example, in the comparative analysis of the structure of slow unaimed motions with and without a weight, the adaptation features were most clearly expressed in the simpler conceptual task action (without the weight). We noted previously that the number and magnitudes of the correction signals decrease as adaptation takes place. While this was quite marked when performing motions without the load, in motions with the load this showed up to a lesser degree. In this case the number of corrections often even became larger than under conventional gravity. /208

The conceptual aspect of the actions becomes even more complex when constructing ballistic motions. The requirement for the development of large forces in short time intervals (0.3 - 0.5 seconds) forces the central nervous system to put the primary emphasis on controlling the motions on the preliminary situation. The initial and final flexion and extension forces become of primary importance. The speed of the actions makes their regulation with the aid of secondary corrections difficult. Therefore it is easy to explain the fact that the performance of ballistic motions stood at the lowest degree of adaptation to weightlessness (the applied forces decreased only slightly; corrections appeared which had not been present in the background performance of the actions). A similar situation existed when performing slow aimed motions, where the conceptual task was complicated by the introduction of a precise target situation. In this case the largest increase of the number of corrections took place in the second half of the extension. This concentration of correction waves in the final motion phase is obviously explained by the fact that the closer to the end of the motion the correction is introduced, the higher is the probability of precise solution of the posed conceptual task.

The importance of the conceptual task complexity for rapid adaptation of the motions to weightlessness is also confirmed in examining the following group of motions, where along with rapidity of action performance, precision was also required. Thus, the performance of rapic aimed extension (striking a target) stood at an earlier stage of adaptation than the performance of the motions examined previously.

The task of the higher coordination centers in controlling work skill modification (working with a hammer) became still more complex. Here, in addition to the fact that the hammer was an additional load, it actually elongated the arm kinematic chain by one member. In the backswing (slow movement) the magnitudes and number of corrections decreased, while in striking (fast movement) they increased. Specifically, the additional correction wave C^1, clearly expressed with respect to the forearm center of gravity (see Figure 21), appeared.

In all the motions, without exception, fixing the elbow to a support led to simplification of the structure and faster adaptation to unusual conditions.

In analyzing the genesis of voluntary motions in a child, A. R. Luriya also noted that the child masters fastest of all /209 those actions which are simple in terms of the conceptual task. Luriya correctly related this with development of the regulating function of speech. A somewhat different pattern was observed in the case of damage of the peripheral apparatus. Leont'yev and Zaporozhets, studying the number of motions in patients with arm bullet wounds as a function of the conceptual action task assigned the patients, found that complication of this task (the introduction of objectivity, for example not simply to raise the arm as high as possible but to reach a target) led to increase of the number of motions. They explain this fact by saying that when objectivity is introduced conceptual afferentation takes on the primary role in action organization, replaces (partially) proprioceptive afferentation and compensates for its deficiencies caused by the trauma.

The seeming contradictions between the results of these studies and our data is explained by the different conditions of the motion study. Under weightless conditions, we were dealing with temporarily disrupted functional interrelationships within the motor analyzer system, specifically between proprioceptive and conceptual afferentation, with anatomical integrity of the motor apparatus. Under these conditions, as the disrupted functional bonds were restored, the characteristic outer ring control functions were transferred to the inner ring from the outer ring by concrete muscle synergies (Chkhaidze). Under these conditions the introduction of objectivity complicated the conceptual task and made it difficult to control the skill from the outer ring.

The situation was different in the case of anatomical damage to the motor apparatus and disruption of the integrity of the peripheral proprioceptive field. Under these conditions conceptual afferentation must partly or completely replace the lost proprioceptive afferentation and compensate (to the degree possible) for its absence. Therefore, when performing actions with a conceptual synergy level task (raise the arm as high as possible) the participation of conceptual afferentation is limited.

This explains the small number of motions. However, upon introduction of objectivity into the conceptual task of an analogous motion (reach a pencil), conceptual afferentation becomes dominant and governs the motion structure. It compensates partly or completely for the lost proprioceptive afferentation and makes it possible to perform a large number of motions.

However, the data of Luriya on voluntary motion genesis and our data on the rapidity of motion restructuring under new conditions of the external medium can be explained on the basis of Apokhin's theory of the functional system. Anokhin (1968) assumes that selective combining of the various structures of the organism into a functional system, in turn, becomes possible only on the basis of heterochrony in the formation rates of development, and moments of consolidation of these structures during the course of the entire embryonic development. In the activity of a functional system (specifically, the motor system) this shows up in the subordination principle. /210

If we now arrange the motions which we have studied in accordance with Bernshteyn's multilevel theory of motion structure, based on sequential phylogenetic development of the central nervous system branches, we find that adaptation occurs first of all for motions of the synergy level, then for motions of the spatial field level and, finally, for motions of the objective action level.

Thus, the motions which are oldest in the phylogenetic series adapt most quickly to new conditions, i.e., the patterns of motor function development in ontogenesis are repeated. For motions of the objective action level using some tool, there is an additional effect on the adaptation rate of the need to interact with the object, which plays the role of a separate member of the arm's kinematic chain.

BIOMECHANICS OF HUMAN ARM MOTIONS UNDER 2-g CONDITIONS

In his day-to-day life man constantly encounters the action of various forms of accelerations and is well adapted to the action of small positive load factors. The development of transport vehicles has posed the task of establishing the physiologically permissible acceleration magnitudes. Many studies of Soviet and foreign scientists have been devoted to this question. These studies have also covered individual aspects of the motor analyzer activity, with primary attention naturally being devoted to disruptions in the blood supply to the brain resulting from large positive load factors. Very little attention has been devoted to small positive load factors, when the phenomena associated with disruption of the blood flow in the central nervous system are not superposed on the acceleration effect.

P. K. Isakov quite rightly points out that, for comparison of the physiological action of different gravity forces, the load factor should be altered in equal units. He considers such equal changes in relation to conventional gravity to be weightlessness (minus one unit) and a 2-g load factor (plus one unit). We shall analyze the changes introduced in the biomechanics of the voluntary human motions by increase of the gravity force by one unit, and the paths the central nervous system selects under these conditions in constructing the motions to achieve a posed objective.

Even in individuals with considerable flight experience, in the Keplerian parabola under the action of a 2-g positive load factor motion coordination did not recover to the original /211 background level associated with the normal load factor. Even the external pattern of the motions reflects deterioration of their coordination. The displacement trajectories of the arm's identifying points lose the smoothness and roundness of the curves, the raising and lowering curves diverge markedly, and the curves become covered with irregularities and wiggles.

The irregularity of the horizontal and vertical velocity component curves also increases. The maximum velocities and the rapidity of the velocity rise and fall at the beginning and end of the motion decrease, particularly with respect to the vertical component.

The maximum magnitudes of the accelerations at the centers of gravity of the corresponding members decrease by a factor of two to four. However, although the accelerations in the vertical component decreased particularly markedly, the applied forces even increased, since it was necessary to overcome the action of the doubled gravity force.

The number of correction signals increased. The magnitudes of the muscle forces applied increased. The leading role of the vertical components on the force curves intensified. The overall applied force vectors took a more vertical direction for facilitation of the action being performed, since in this case the angle between the gravity force vector and muscle force directions decreased (see Figure 20, left half). The reverse pattern was characteristically observed under weightless conditions. The absence of the need to consider the action of an external force led to a situation in which the applied forces took a flatter direction, since in this case the angle between the force and the direction of the motion decreased. This is reflected indirectly in increase of the horizontal components role on the force curves.

Thus, doubling of the gravity force led to complication of the motion structure. The role of the central nervous system in controlling the motions increased, the number of correction signals increased, and the magnitudes of the forces applied increased. This agrees with the data of Chkhaidze, who showed the dependence of the degree of motion coordination disruption on the magnitude of the logarithm of the load factor, but he used large load factors in his experiments, which caused disruption of the blood supply to the brain.

However, the role of positive load factors in the motion is not always negative. In the higher skill mastery stage the central nervous system uses the gravity force in the interests of constructing the motions. This has been noted previously, but experiments recently conducted make it possible to examine in more detail the characteristics of this process with increase of the load factor from zero to two. These characteristics show up most clearly on the overall muscle moment curves (see Figure 21).

We noted above that, under conditions of the conventional gravity force, when performing work with a hammer the accumulated kinetic energy is greater in the backswing than in the striking part of the motion itself. /212

This relationship shows up still more vividly in the load factor two case (and, as mentioned above, in the zero load factor case). For example, the ratio of the peak muscle moment to the negative moment in weightlessness for subject L when striking with a hammer is 1.16. Under the action of conventional gravity this ratio increases to 2.2, and under the action of a 2-g load factor it becomes equal to 3.4. This is explained by the fact that under the action of the doubled gravity force additional work is imposed on the flexor to overcome the increasing external resistance, while the extensor work is correspondingly facilitated, i.e., the nonuniformity in the work distribution between these muscle groups increases.

In the process of motion performance there is not only competition with the action of the gravity force (Bernshteyn), the action of this force is also utilized in the interest of constructing the motions. In accordance with this hypothesis, with increase of the gravity force from zero to two units, there is an increase of the nonuniformity in the work distribution between the forearm flexors and extensors in the initial and final parts of flexion and extension.

Moreover, analysis of motion structure under different gravity conditions shows that with increase of gravity from zero to two units the motion coordination structure becomes successively more complex. This makes it possible to suppose that under conditions of reduced gravity, in particular under the action of the lunar gravity force (one sixth g), the motion coordination structure after passing through the adaptation stage will be simpler than under the action of the earth's gravity force and more complex than under weightless conditions, since increase of the gravity force from zero to two units complicates the external interaction at the periphery, which leads to an increased role of the central nervous system in the motion regulation.

Increase of the number of the arm's kinematic chain members participating in the motion led to more complex interaction of the forces of muscular and reactive-inertial origin. A direct dependence was found between the complexity of the motion coordination structure and the complexity of the internal force interaction at the periphery under normal gravity force conditions. Under conditions of change of the complexity of the external force interaction (weightlessness, positive load factor of two, water immersion), the dependence of the motion structure complexity on the nature of the internal force interaction showed up still more clearly. The magnitudes of the applied muscle forces increased, the number of acceleration and muscle moment curve irregularities increased, reflecting participation of the central nervous system in the motion regulation.

Thus, central regulation of voluntary motions permits /213 man to perform motor activity under various conditions of force interaction at the periphery. The dependence of the motion structure complexity on the nature of the external and internal force interaction at the periphery, established by Chekirda, can serve as the basis for creation of a unified theory of force inputs (and specifically gravity inputs) on motion structure.

MOTOR ACTIVITY OF MAN IN SUPPORT-FREE SPACE

Man's motions in support-free space were subjected to careful study in connection with the preparation for man's sortie from the spacecraft into open space. The studies were made in a flying-laboratory airplane with a "weightless pool." It was found that individuals exposed for the first time to support-free space lose the ability to control their motor reactions. At the moment of weightlessness onset, many subjects instinctively begin to make "swimming" motions with their arms and legs. They sort of try to hold themselves in the air, much like people flounder around when they first fall into a deep spot in the water. Later on coordinated, "smooth" movements develop. While initially the subjects "fly" from one wall of the pool to another because of strong pushes, in the process of the training sessions the subjects learn to maintain body stability in space or, as they say, "hover."

Cosmonauts Nikolayev and Popovich freed themselves from the restraint system in order to study motor reactions in the support-free state during orbital flight. As they released the restraints, they noted an involuntary displacement of the body toward the "ceiling." In all probability this effect can be explained by rotation of the ship around the center of mass. Although this rotation takes place very slowly, it is sufficient to develop a small centrifugal force. However, Nikolayev and Popovich reported that it was not difficult to fix the body in various attitudes and rotate the body about an axis.

It should be emphasized that, although the cosmonauts were in the support-free state, in all cases they were restricted in space to the inside of the flying-laboratory airplane or the spacecraft cabin. The subjects could "float" up to a support, fix their position with the aid of the support, or could push away to obtain momentum for movement. One of the cosmonauts reported: "In order to perform rotational motions it was necessary to push off from the floor with the hand. Thereafter the rate of rotation depended on the posture. To /214
increase the rotation rate the arms and legs were tucked in close to the body, to slow down they were extended."

A fundamentally new and far more difficult task was assigned to Leonov in leaving the spacecraft and going out into open space. Here he had not only the problem of orientation but also motion coordinations in nearly "pure" support-free space, no longer restricted by the cabin walls.

In the last century, many mechanists believed that a living being could not turn his body in the support-free situation around any axis. They used as their main argument the law of conservation of moment of momentum (law of conservation of areas). Thus, the well-known French mathematician Delaunay in his book "Mechanics" in 1862 wrote: "If we assume that a living being is isolated in space and that no external force is applied to him, then not only will this living being not be able to displace his center of gravity, but in addition it will be impossible for him to impart rotation to his body about this point. Actually, no matter how he uses his muscles he can develop only internal forces; the absence of external forces leads to the consequence that the sum of the described areas, projected on an arbitrary plane passing through the center of gravity, maintains a constant magnitude; consequently this sum must remain at all times equal to zero."

The error of this statement was proved by Marcel Deprez. He made a series of photographs of a falling cat, which could without difficulty always turn with his feet down. It was found that this fact could not be explained from the viewpoint of the fundamental law of mechanics — the area conservation law.

In his book "Conversations on Mechanics" published in 1907, Professor V. Kirpichev showed that rotation of the cat takes place in support-free space in complete accord with the law cited above. He wrote that "a man or an animal cannot impart to himself that rotation which a top or other completely unchangeable body acquires. But living creatures can impart to their individual members varied motions: they can turn their arms or legs relative to the remainder of the trunk and thus select these motions so that they compensate for the rotation of the entire trunk, i.e., these additional motions of the arms or legs yield an area which is qual but opposite in sign to that area which the remainder of the body describes as it turns about some axis. Thus the phenomenon of this rotation will not contradict the area conservation law" (cited in Stepantsev, Yeremin, Alekperov, 1965, p. 48).

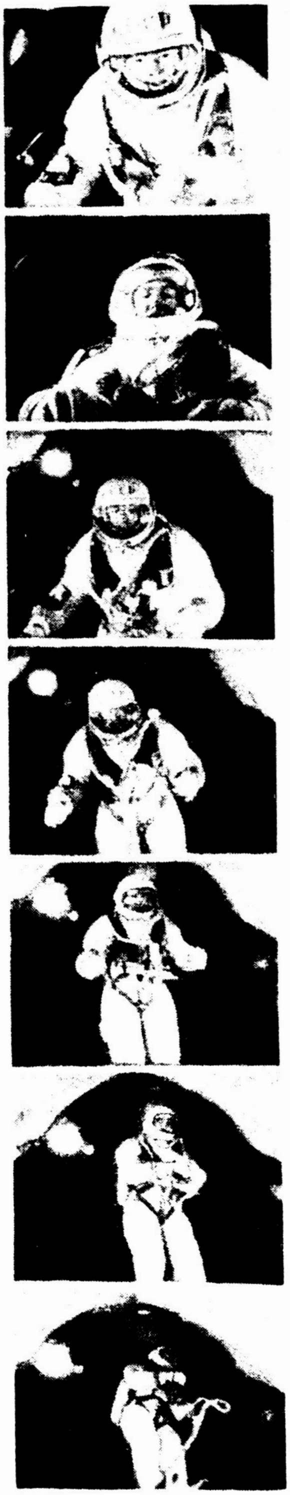
Thus, Kirpichev's calculations showed that man can rotate his trunk relative to any axis without interacting with external bodies, provided he rotates some other part of the body in the opposite direction. This conclusion was confirmed /215 on the "Zhukovskiy bench." The latter consists of a horizontal platform supported on ball bearings. This provides rotation of the platform in the horizontal plane with practically no resistance. If a man stands on such a platform and describes with one arm a conical motion above his head, he will impart to his body a rotation in the opposite direction without the action of an outside force.

Stepantsev, Yeremin, and Alekperov worked out groups of arm and leg motions for rotating the body around its transverse and longitudinal axes under experimental conditions simulating the support-free state on the "Zhukovskiy bench" and in exercises on a trampoline. The results of the studies made it possible to establish that after some preparation an individual can, even during support-free "swimming" under weightless conditions, orient his body quickly and precisely in any direction simply as a result of muscle forces, without resorting to the use of any hardware. However, we note that the subjects performed their actions while not outfitted in a pressure suit, and the latter will restrict considerably the individual's motions.

Prior to the first sortie of man from the spacecraft, a special training program for working out the motions in support-free space was conducted. The training took place in the flying-laboratory airplane, where a mockup of the Voskhod-2 spacecraft with the full-scale airlock chamber was installed. In this training the performance of the basic flight mission — the exit into space and return into the spacecraft — was conceived (and correspondingly worked out) in the form of a series of sequentially performed operations. Prior to entering the airlock the cosmonaut was to don the backpack with the autonomous life support system and connect up to this system.

Then followed a check of the equipment used in exiting from the ship and equalization of the pressure between the airlock chamber and the cabin. Then the cosmonaut entered the airlock chamber, where he checked the pressure suit and helmet for leaks, verified the light filter position and oxygen flow. After this the ship commander closed the cabin hatch, released the pressure in the airlock, made the planned number of departures from and returns to the airlock, and finally returned to the cabin. In all he had to perform about six operations while restrained in his working area, the pilot's seat; eight in the unrestrained state during movement in the cabin; and four in the support-free state outside the spacecraft. The training in performing all these operations developed a very definite pattern.

It was found that restraint in the working area provides quite high efficiency of the performance of the operations scheduled in the flight plan. Only in the first two weightless flights were changes in motion coordination (blunders) observed. In the subsequent flights there were no such errors. However, the movements in the unrestrained state when moving about inside the ship and airlock were more difficult to perform. Here the cosmonauts evidenced lack of reliable support to some degree. They could only touch the sides of the ship and the airlock. In addition, the nature of the working operations was more complex. Many muscle groups of the body and the extremities were involved in performing these operations, as a result of which the motion coordination changes were more marked. The efficiency in performing the operations depended to a great extent on the force of the contact with the wall of the ship or airlock. If energetic pushes were used the transit through the airlock was quite rapid; however, danger of striking surrounding objects /216



arose; in the case of weak pushes the exercise was often not completed. The presence of special equipment in the form of the pressure suit also complicated the situation considerably, particularly when pressure was maintained in the suit to simulate the inflated pressurized suit under space vacuum conditions.

As for the approaches to the ship and particularly the movements away from the ship, here the required skills were by no means worked out immediately. The criterion for performance of the exercise was the smoothness of the motion and the duration of the operation (Figure 23). According to Leonov's report: "The very first sortie was the best but could not be repeated. During one "hump" I left the airlock and re-entered it." This success is explained to a considerable degree by the repeated and attentive examination of movie films which recorded the corresponding actions of two subjects, /217
by the equally repeated "dry run" in

Figure 23. Cinegram of Leonov leaving the airlock chamber in the "weightless pool" set up in the flying-laboratory airplane.

the mind of all the required operations, and by the accumulated personal experience in weightless flights. Yet, after the initial success several training sessions were required before Leonov was able to again reproduce the first maneuver. Six attempts were required just to work out the skills in performing a smooth exit from the airlock, and four attempts were required to work out the problem of approach to the airlock. Initially the movements were abrupt, with rotation of the body about both the vertical and horizontal axes. During the first three flights, 19-20 seconds were required to perform the sorties, while about 6-8 seconds was required in the last flights. However, no reduction of the time was observed in working out the approaches to the airlock. Rather the time required increased. During the first approaches, very little time remained for this operation and the cosmonauts hurried, and this led to less efficiency of the task performance. The subjects did not approach the airlock smoothly but rather jerkily and with rotation to the side, or even with their back to the airlock. However, at the end of the training cycle the departures and approaches were performed normally and with optimum time expenditure. Thus, Leonov wrote the following in his report on this period of the training: "The flight went well. I did not feel any unpleasant sensations. The sensations were the same as those noted previously during weightless flights. The pressure suit restricts movement somewhat and the pressure helmet reduces the field of view. The approaches to the airlock were performed easily, since I tightened the tether and thereby created a point of support and determined the direction of motion. The approaches and departures should be made smoothly.

It appears that under weightless conditions the presence of even the slightest point of support makes it possible to perform any operations without marked disruption of motion coordination."

Leonov completed five departures and approaches in space (Figures 24, 25), with the very first departure being made to a minimum distance of one meter for the purpose of orientation in the new conditions. All the motions were performed in the same sequence as had been used in the training sessions. During the first departures there were rotations of the body to the side and backward, in the later departures the exercises were accomplished correctly and confidently, indicating the adaptability of the organism to the unusual situation in support-free space.

The analysis of Leonov's motor activity during the sortie into support-free outer space was made by Popov and Khachaturyants on the basis of special prosessing of movie film data made using an on-board movie camera. The frame rate was 24 frames per second, which made it possible to record quite accurately the individual phases of the cosmonaut's movement and carry out the corresponding analysis. Because of the fact that in several cases the cosmonaut moved out of the frame, a complete analysis was made only of two departures from the spacecraft and a single approach. To study the departures and approaches /219 recorded on the movie film, several characteristic parameters of the movements were calculated to obtain a quantitative description of the motions. These data were compared with the parameters obtained while performing similar exercises during the

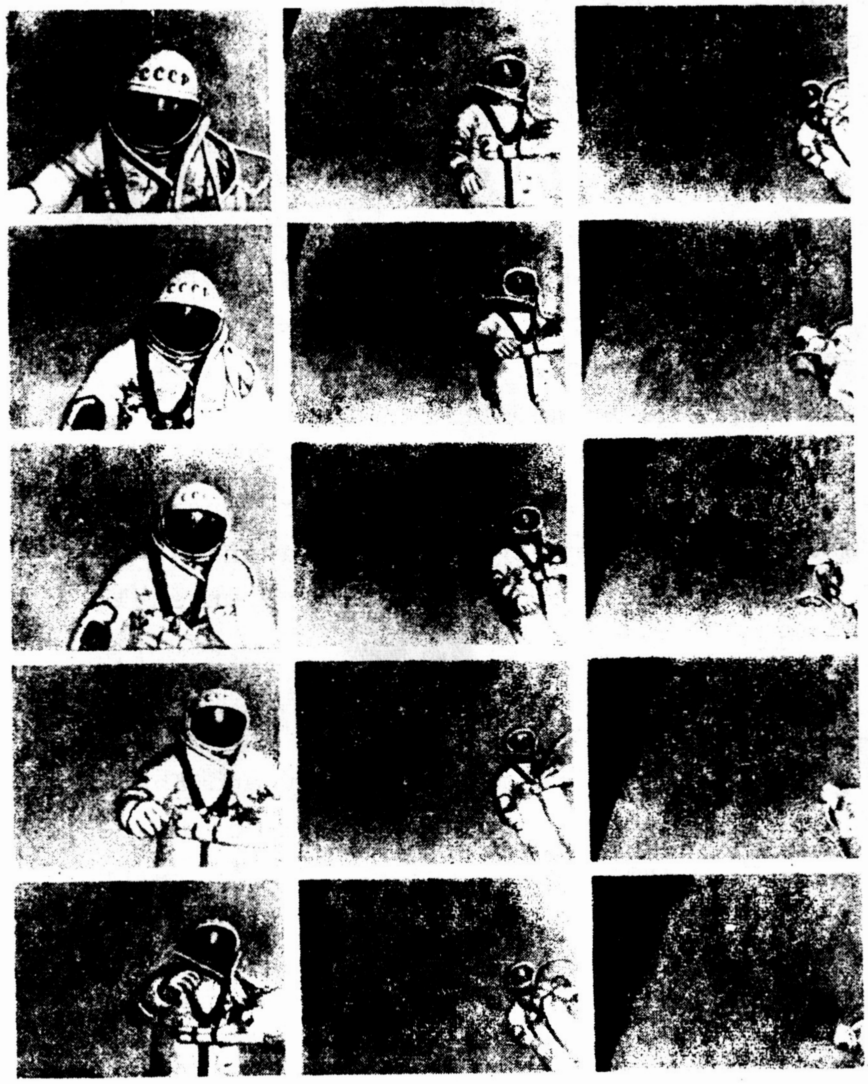


Figure 24. Cinegram of cosmonaut Leonov moving away from spacecraft in flight.

final flights in the flying-laboratory airplane. The analysis made showed that the characteristics of the motions made in performing sorties from the ship in space differ very little from the same characteristics under the conditions of the training sessions in the airplane. In both cases the time for performing the departures amounts to about four seconds. The /220 same can be said of the time for performing the approach to the ship, which in both cases is about 10 seconds. The magnitudes of the average motion velocities differ somewhat more than this. On the average this difference amounts to 20 - 30% of the magnitude of the velocity during the airplane flights, while the maximal values of the difference reach 50%. The results of performing the exercise in space indicate that the training sessions

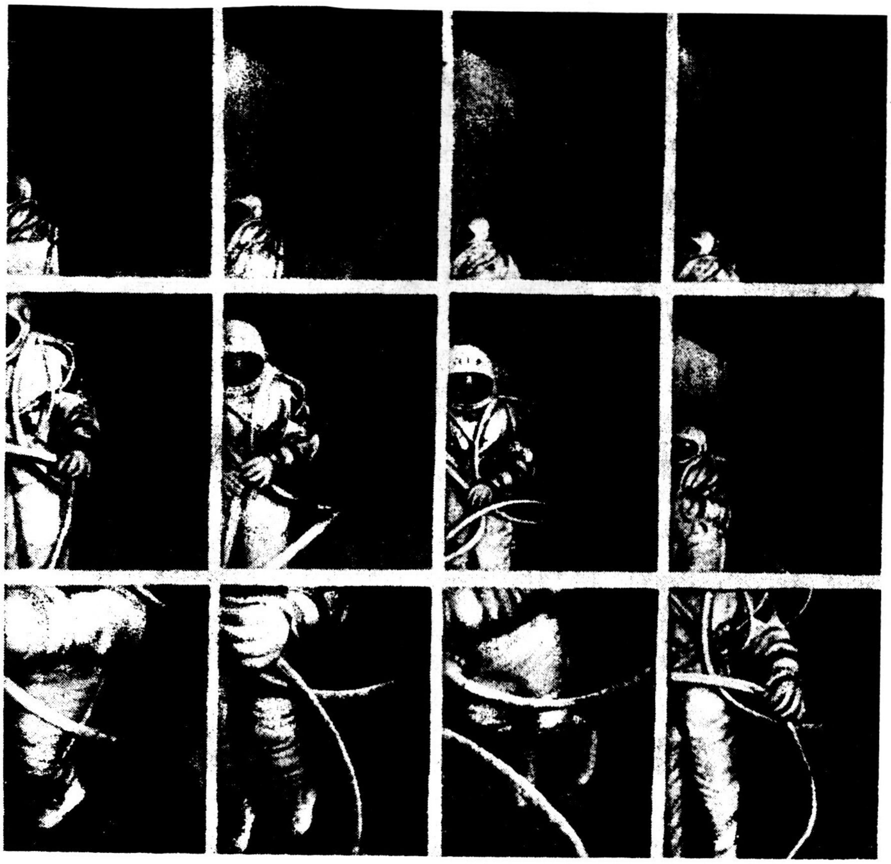


Figure 25. Cinegram of cosmonaut Leonov approaching the spacecraft during flight.

performed during the weightless flights not only made it possible for the cosmonaut to orient himself in such unusual conditions, but also made it possible to perform coordinated motions in accordance with the flight plan.

The efficiency of the exercise performance in space in comparison with its performance in the final training sessions, if we take the latter as 100%, was lower by only 30 - 35% (and at the same time the performance achieved during the first training sessions was exceeded considerably).

The rotations made by Leonov about the vertical axis of the body through 90° were performed very well. The time for each rotation did not exceed two seconds. Worthy of note in these turns is the skill developed during the training sessions in controlling his movement while using his hand to hold on to the tether, located near the center of mass of his body. This is a necessary condition for efficient performance of the motions, and failure to observe this condition may lead to "twisting," i.e., uncontrolled rotation of the body. However, something like "twisting" took place during the sortie into support-free space, when the angular rates of rotation of the body about the sagittal axis reached tens of angular degrees per second and the angular accelerations reached hundreds of degrees per second. The changes of the body rotation angle, angular velocity, and angular acceleration of this rotation with respect to time in the plane parallel to the movie camera focal plane are shown graphically and illustrated by a series of frames from the cinegram of the "twisting" (Figure 26).

In spite of the "twist" the cosmonaut performed completely and efficiently all the scheduled working operations during the sortie from the spacecraft. He installed and removed the cine

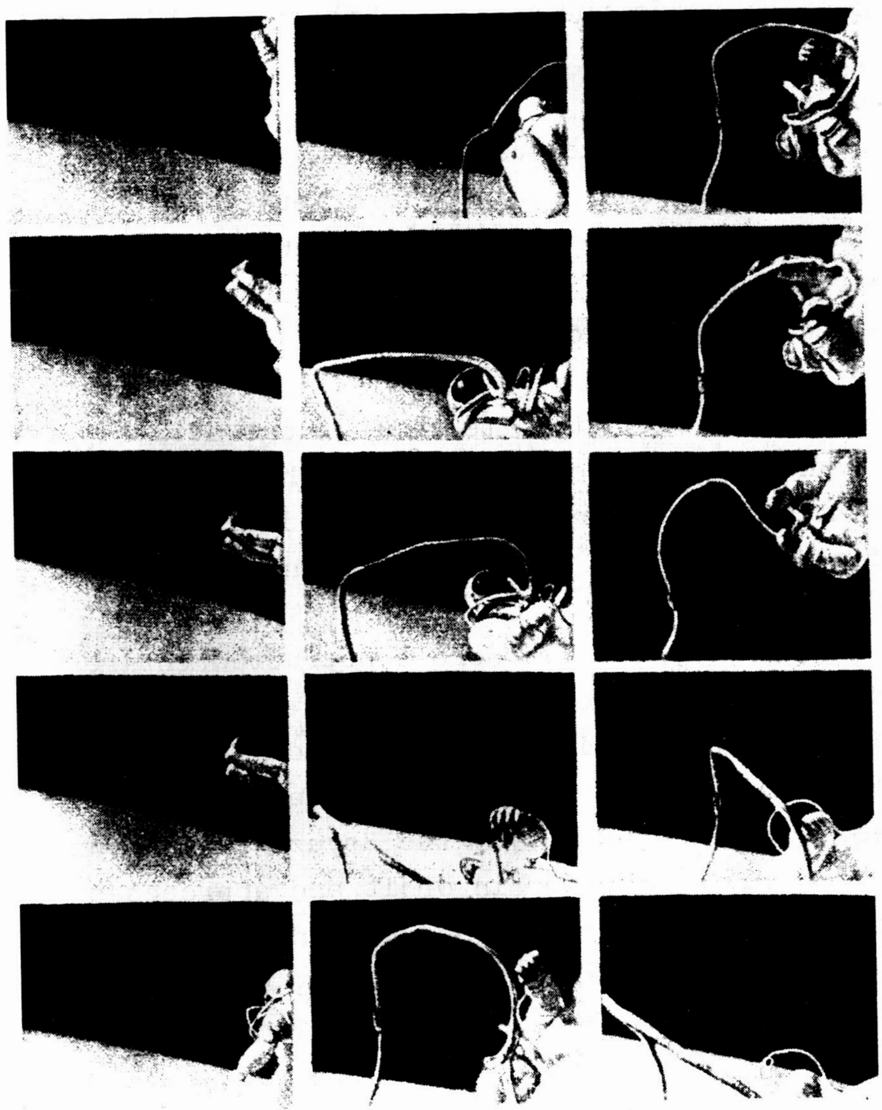


Figure 26. Cinegram of Leonov's "twisting" process in open space.

cameras, made observations and gave real time reports. On the whole we can conclude that in performing the movements and orienting himself in outer space the cosmonaut performed his mission completely.

As is well known, the American cosmonaut White also made a sortie into support-free space. In this maneuver he was restrained to the spacecraft by a 25-foot tether and was outfitted with two movie cameras and a "space gun," which permitted him to maneuver with the aid of reactive air jets.

The reports indicate that White moved about actively in support-free, near-earth space and performed his flight mission. In so doing he noted under the weightless conditions marked disruptions of orientation in space and motion coordination.

Prior to 1969 all spacecraft were constructed entirely on /222
the earth, and after separation from the last stage of the booster rocket and injection into orbit they were ready for operation. It was only necessary to extend the antennas and open up the solar batteries. On 16 January 1969 the Soyuz-4 and Soyuz-5 spacecraft carried out a maneuver in orbit and approached to within 100 meters of one another. Then cosmonaut Shatalov took over manual control and performed the docking, after which mechanical latching, hard mating, and connection of the electrical circuits of the two ships took place. In this fashion the world's first orbiting artificial earth satellite was assembled and the experimental space station began functioning.

This experiment, performed for the first time in the world, is of immense importance for the further development of manned flights and creation of large orbital stations.

Plans have been made for the assembly of large orbital stations in orbit from sections and units delivered from the earth by rockets. Each section may be, for example, a special-purpose laboratory or a living compartment and may have equipment which after assembly of the station will become a component part of the overall power-supply and crew life-support system.

When using orbital assembly, it will be impossible to do without external operations performed by cosmonaut-assemblers, performance of external inspection, and also repair operations. This was the reason behind the transfer of Khrunov and Yeliseyev from one spacecraft to another through open space. This transfer not only made it possible to check the capabilities of man to perform assembly operations but also crew change on the long-life orbital stations.

At a press conference Khrunov discussed in detail the performance of the flight mission program. We shall cite only some excerpts relating to the question under discussion here.

"I left the ship easily and looked around. The Soyuz-4 and Soyuz-5 ships presented a tremendous sight. I could see the smallest details on their surface, the ships reflected the solar light and shone brightly. Soyuz-4 was right in front of me, very much like an airplane — the large, long ship looked like a fuselage and the solar batteries looked like wings. At this time the orbital station was over South America.

"Admiring this amazing pattern — the shiny spacecraft on the background of the earth and the black sky — I began to move around, walked over to the docking fitting area where a movie camera was mounted externally on Soyuz-5 to photograph the mooring and docking of the two spacecraft.

"I should refine the concept 'walked over.' To us, living on the earth, the concept of displacement or movement is usually associated with walking. Under weightless conditions it is not possible to walk over the surface of the ship in the conventional sense of the word — there are no supports for the feet, no forces pressing the individual down against the surface. Back on the earth, in the training sessions we found that it is best to move around the ship from one place to another on the hands, using rigid railings for support. /223

"Thus, grasping the railings, I moved over to the movie camera. Holding the railing with one hand, I used the other to take the movie camera from the bracket and disconnected its electric power plug from the side of the ship.

"And then I went hand over hand along the surface of the orbital station into the Soyuz-4 ship module. With the top half of my body remaining outside, I made observations of the earth's horizon, checked the operation of the orientation engines, talked with the ship's commander, removed the Salyut camera from the orbital module, and took several pictures of the spacecraft.

"When we came into range of radio communication with the tracking stations in the Soviet Union I pulled in the movie camera, taken from the bracket on Soyuz-5 as I came by, placed it on a special bracket at the hatch of the Soyuz-4 orbital module, and connected the electric power. Then this camera was used to record Yeliseyev's exit from the hatch and transfer in space from Soyuz-5 into Soyuz-4.

"I should mention that the operations involved in removing and mounting the movie camera under space conditions, and photography with the hand-held camera, are by no means simple. One has to be restrained in the working area."

In addition to the operations listed above, in open space Khrunov and Yeliseyev installed and then folded up the railings for leaving the orbital module and transfer into the other ship, installed and disassembled the television lights, and simulated several assembly operations which may be required in assembly of large orbital stations.

We should also note here that the pressure suits used for working in space in this flight differed from the suit in which Leonov made his sortie into support-free space. In developing the later suits, use was made of all the experience in cosmonaut operations in open space. Describing the new suit, Yeliseyev said: "The suit is comfortable, the joint flexibility is good, which makes it possible to perform various assembly operations in space. The suit ventilation and heat transfer are such that we were not too warm while performing the operations outside the ship and while transferring. Nor was there any fogging of the faceplate."

The transfer from one ship into the module of the other ship through open space showed that under these unusual conditions it is possible to perform such operations as assembly of equipment, spacecraft crew replacement, and rescue of the crews of spacecraft which have suffered damage in orbit.

CHAPTER 5

SPACE FLIGHT WATCHKEEPING AND PSYCHOPHYSIOLOGICAL RHYTHMS

We have already mentioned that during interplanetary spacecraft control in long-duration flights the cosmonauts will be part of the "man-spacecraft-space" system. The primary function of the operator in this system in the case of normal system operation is observation of the instrument indications. However, the cosmonaut's activity will differ from conventional operator activity, for example, at the control station of a modern electric power station. The spacecraft operator must perform several functions in parallel, and these functions may be associated with fields of science and engineering which are quite different from one another. For example, monitoring the operation of the closed or semiclosed cycle ecological life support equipment requires biological knowledge, while monitoring the flight conditions and trajectory requires astronomical and navigational knowledge. In general form the functions of the cosmonaut-operator will amount basically to compensating tracking of several indicators, operations involving monitoring the magnitude of the regulated vehicle parameters, mathematical and logical analysis of the information coming from the instruments and warning systems, analysis of the monitoring results and comparison of these results with the program, arriving at a solution regarding control of the vehicle, and carrying out this solution. /224

We should mention once again that during long space flights it is by no means impossible that there may be failures of particular devices and systems, possibility of the occurrence of unforeseen complications which require the cosmonaut to make an emergency transition from observation to actions. It is practically impossible to foresee all the possibilities of deviations in the operating conditions of the various mechanisms, all the malfunctions and emergency situations. It is only as a result of intelligent steps taken by a man having extensive knowledge and experience that it is possible to cope promptly with unexpected situations and random occurrences. Therefore, the cosmonaut on duty must always be in a state of high readiness for action. Speaking in the language of cybernetics, the cosmonaut-operator must perform the role of a "biased circuit." It is the readiness for action which is the important factor in the reliability of man as a link in the "man-machine" system, for it determines the effectiveness of the required intervention of man in the course of events. /225

Here a question immediately arises: how long can a cosmonaut who is on duty remain in a state of adequate readiness for action, or, in other words, when does he become so tired that this may affect the efficiency of his operator activity? An entirely definite answer to this question can not be given at the present time. However, using the data accumulated by work physiology and psychology we can today determine with some degree of confidence the optimal duty time in space flight.

SPACE FLIGHT WATCHKEEPING

Thus, during extended interplanetary flight, in the case of failure-free operation of the automated spacecraft systems the control station operator will be limited to simply observing the indications of instruments and indicators. This is an activity with essentially inhibited motor end. It is true, as indicated by Gurovskiy, that some functions of such an "end" take on subjective representations, which arise in the second signal system in the form of conclusions of the "all normal" type. The absence in the course of tracking activity of afferentation from the muscular and articular apparatus, the tactile sense, and the other sense organs, which arises during normal operation, makes the cosmonaut's work monotonous.

While on the ground it is possible to switch the individual in work process to various forms of work, under space flight conditions it is difficult to alter the stereotyped monotonous working and living situation. This is associated, first, with the limitation of the ship's interior volume and, second, with the relatively small number of crew members.

Characterizing the working process, Marx wrote: "In addition to tension of those organs which perform the work, in the course of the entire working time it is necessary to have goal-directed volition, which is expressed in attention, and this is all the more necessary the less the work attracts the worker by its content and means of performance ..."[1]. Among the various qualities of attention, those most important in regard to professional activity are: intensity (more precisely, concentration), stability, rapidity of switching, and breadth of distribution. Attention itself is "due to that organization of activity in which we perceive clearly definite concepts, thoughts, or other senses, while others withdraw into the background or are not perceived consciously at all" (Platonov, 1962, p. 41). /226

[1] K. Marx and F. Engels, Works, Vol. 23, p. 189.

Characteristic of the operator's profession in automated systems is high attention intensity nearly throughout the duty period. But Marx long ago noted that "continuous monotony of the work weakens attention intensity and energy lift, since it deprives the worker of that relaxation and stimulation which are created by the very fact of activity change."[2] This idea has been confirmed in specially conducted experiments and in the course of work processes for individuals of the so-called observational professions.

A large number of studies have been made which indicate the negative effect on an individual of monotonous forms of work. The experimental studies of S. A. Kislov, conducted at the Institute of Work Hygiene and Occupational Illnesses of the Academy of Sciences USSR, indicate that when performing unvarying, monotonous work the functional mobility of the basic nerve excitation and inhibition processes is diminished at the end of the working day in proportion to the degree of monotony of the work being performed. In this case the duration of the time required for performing the work operations increases markedly. His experiments showed that the functional mobility change takes place primarily in the analyzer which has the greatest participation in the work. For example, in the case of work on a conveyor line functional mobility change is observed in the motor analyzer, in the case of proofreading work this is observed in the visual analyzer.

According to McWard's data, fatigue develops particularly rapidly when working with oscillographic indicators. Vision fatigue occurs after 30 minutes. He suggests the use of certain

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(2) K. Marx and F. Engels, Works, Vol. 23, p. 353.

pharmacological substances (stimulators of the benzedrine or amphetamine type) to prevent fatigue under these conditions and when maintaining vigilance.

F. P. Kosmolinskiy writes that in the 1950's, when automation (autopilots and other automatic instruments) were first introduced into aerial navigation, cases were noted of extensive pilot fatigue. There was an obvious influence of the monotonous situation under conditions when the pilots simply observed the instrument indications.

In the reports of cosmonauts Nikolayev and Popovich it was noted that during flight they performed all forms of work easily and felt fine. However, according to Sisakyan and his colleagues, certain physiological indices and the work capacity at the end of the flight indicated cosmonaut fatigue. Six hours after land- /227
ing, observations showed increase of pulmonary ventilation, 24% increase of oxygen consumption, and 30% increase of carbon dioxide release. Corresponding changes indicative of fatigue development in the cosmonauts were also noted in brain cortex bioelectric activity change, which appeared as increase of the alpha rhythm.

Tereshkova also evaluated her condition in flight as good. However, analysis of the telemetry data led Yazdovskiy, Bayevskiy, et al. to conclude that after several hours in weightlessness her motor activity had decreased. At the end of the flight a frequency shift in the direction of slower rhythms was noted on the brain potential electrographic curve. The shifts in the various functional systems (cardiac cycle phase, breathing, gas interchange of gases, electroencephelogram, and so on) noted in Bykovskiy after termination of the flight also corresponded in general to the picture of marked general fatigue.

After analysis of the literature data and recordings of the physiological functions, Yeremin, Kas'yan, Kolosov, Kopanev, and Lebedev came to the conclusion that when cosmonaut working activity becomes more complicated and there is an increase of the flight duration, reduction of the work capacity is observed in many cases. This was also indicated by the requests of the American astronauts to omit several planned television transmissions to the earth during circumlunar flights because of fatigue.

One of the factors leading to development of fatigue in space flight, in addition to weightlessness and other factors, is the reduction of the stimulus flux incident on the sense organs of man accustomed to living under conventional earth conditions. This is vividly demonstrated by the experiments of the American investigators McKenzie and Hartman, who studied work capacity in the cabin of a spacecraft trainer. In the course of their experiments the subject was exposed to individual light signals to which he was supposed to respond in a definite fashion. If the signals were displayed at a rate of 3600 per hour it was found that the individual was overloaded with information. With a signal display rate of 350 - 400 per hour the operator worked normally. But when the rate was decreased to 40 signals per hour, the operators began to work significantly more poorly. Failures to react to the signals became more frequent.

The systematic study of the influence of sensory deprivation on work capacity in relation to aviation and space psychology was initiated abroad in the 1950's. Extensive scientific data have been accumulated on this subject and hundreds of papers have been published. The experimental conditions were extremely varied. Various techniques and approaches have been used to limit the /228 information inflow. In several cases the subjects were placed in special water-filled tanks, darkened boxes, and isolation chambers.

In analyzing the results of the experimental data, Kosmolinskiy subdivides all the changes taking place in the organism under the influence of limitation of the sensory information into three basic groups: (1) changes of the brain cortex functions; (2) changes of the emotional sphere; (3) vegetative changes.

Experiments with stimuli limitation under isolation conditions conducted by Soviet scientists have shown that the healthy individual with high spiritual and willpower qualities can stay for a long time in an isolation chamber without any psychic changes which threaten the state of his health. The onset of various unusual psychic states up to some definite time does not have a pathological nature. The sensory isolation experiments also showed that in order to maintain the individual's work capacity under these conditions it is necessary to take a broad complex of measures directed toward varying his activity, elimination of sensory deprivation during relaxation periods, and so on. In the course of the experimental studies it was found that the working day must be standardized for operators occupied with observation of instruments and making decisions on the basis of their indications.

In studying the work-rest regime of television studio control console operators, A. I. Kikolov found that the physiological function indices reflect positive adaptation to the work in the course of the first three or four hours, after which progressive deterioration of the work capacity occurs. He recommended limiting the duration of control console work in the course of the working day to four and a half hours. His view is that it is advisable to utilize the control console operators in other operations for the remainder of the time (two and a half hours). Moreover, in the course of work at the console, Kikolov suggests the assignment of three mandatory ten-minute rest breaks in the course of the working period, assuming that with the aid of these breaks it is possible to prevent early onset of fatigue for workers in this category.

A study by Meville Janes showed that during highly intense and long-duration flights the normal duration of the radio operator's work is three hours. According to his data, longer working periods lead to progressive deterioration of work efficiency and tension and irritability increase.

A study of Suvorova, Idashkin, and Gaszhiyev on the experience of operators in modern automated electric power stations shows that even duty periods which are at first glance easy and during which the personnel do not perform any operations, but are rather occupied exclusively with surveillance and waiting /229 for emergency breakdowns, lead to exceptionally marked nervous tension. At the end of the shift the operators are not capable of performing any mental activity, sleep poorly, show marked irritability, and so on.

Numerous data of Soviet and foreign scientists show that after five to six hours of observing (even in the case of normal operation of the automated devices), the individual's alertness gradually decreases. There is a corresponding decrease of his reliability as an element in the "man-machine" system. The investigators note that negative emotions have a large effect on fatigue development.

If we consider that the cosmonaut will be subjected to several unfavorable factors (including long flight duration), we see that we can expect fatigue to develop sooner than five or six hours during space watchkeeping, and the optimum working time under these conditions will apparently be a period not exceeding four hours (with mandatory preliminary active relaxation and sleep). This conclusion is confirmed to some degree by the experience of extended autonomous submarine voyages, when the crewmen serve a four-hour watch.

BIOLOGICAL RHYTHMS OF ORGANISMS

> We must understand what man is, what life is, what health is, and how equilibrium and harmony of the elements support good health and how their discord destroys health.
>
> Leonardo Da Vinci

In the process of evolutionary development of plants and animals, there have developed several physiological adaptations to the periodic geophysical and meteorological changes associated with rotation of the earth about its axis and revolution around the Sun (onset of light and dark periods of the day, increase of temperature and solar radiation in the daytime hours, change of the humidity and barometric pressure of the air in the nighttime hours, changing of the seasons, and so on). One of the most characteristic adaptations of this sort is the daily rhythm of sleep and wakefulness. This is evidenced in reduction of the body temperature, pulse and respiration rates, metabolism, and other physiological functions of the organism at night and increase of these factors in the daytime. About 40 different human physiological reactions have been recorded whose intensities are intimately connected with the time of day. Even such /230 phenomena as birth and death rates have diurnal periodicity. According to Halberg's data, these rates are highest between 11 o'clock at night and one o'clock in the morning.

It is obvious that it will be difficult (or entirely impossible), at least in the first interplanetary flights, to maintain the life activity rhythm of the people aboard the spacecraft which is normal for conditions on the earth.

Suffice it to say that in orbital flight the change from "day" to "night" will take place quite frequently. Thus, in the course of one day Titov encountered 17 "space dawns." However, in interplanetary flights, which may last for many months or even years, the periodic diurnal and seasonal changes which are so customary for life on the earth will not be observed at all. Finally, when one lands on any particular celestial body the alternation of day and night will again differ markedly from conditions on the earth (for example, on the Moon the days last nearly a month by earth time).

In this connection it becomes urgent to study how space flight conditions affect the human biorhythm and the limits within which the biorhythm can be rearranged without damage to the organism.

The study of the biorhythmicity of living organisms was initiated more than 200 years ago. In 1729 the astronomer de Meran discovered that plants kept in the dark at a constant temperature showed the same periodicity of leaf movement as plants kept under conditions of conventional alternation of light and dark in the course of the day. Experiments of this sort were extended in later years to completely different organisms — ranging from single-cell organisms to human beings. As a result it was possible to establish that even the very simplest living creatures, when exposed to conditions of constant illumination (or darkness), maintain activity-rest, growth, division, and so on variation rhythms approaching the values which are characteristic for conventional conditions. Halberg termed such rhythms "circadian" (from the Latin words: circo meaning about and dies meaning day).

The series of experiments conducted with flying squirrels, which lead a nocturnal form of life, is of interest. The animals were placed in a cage with an exercise wheel equipped with a device for recording the number of revolutions and kept in the dark for several months. The curves of squirrel activity obtained showed quite clearly that the squirrels became more lively each evening. The running in the wheel began each time after the same time interval, about equal to a day.

A series of experiments with mice showed that the same spontaneous frequency of the physiological functions (motor activity, sleep-waking phases, and so on), approaching the /231 circadian frequency, was maintained in six generations of these animals kept constantly in the light. Also of interest is the communication of Bunig on the circadian variations maintained in an isolated hamster intestine cell placed in a physiological solution. Data are also available on the circadian periodicity of cell splitting in mammalian tissue cultures.

Of considerable scientific interest in this regard are observations made of members of an Arctic expedition, where the sunrise and sunset factor is absent for many days. From the results obtained by Lobban, who made studies in Sptizbergen during the polar day period, we see that continuous two-month illumination does not affect markedly the circadian rhythm of the physiological processes of people arriving from the middle latitudes, who continued to work and rest in their usual regime.

We also see from the data of Boriskin, who made observations in the Antarctic (polar station Novolazarevsk, located at 70°46' south latitude), that the polar night and day had no significant effect on the daily physiological function periodicity of individuals who stayed through the winter.

Thus, in accordance with the present scientific view, physiological rhythmicity of the circadian type shows up for all forms of plants and animals exposed to so-called constant conditions. This factor is associated with the idea of the existence in the organisms of "biological clocks" which regulate the physiological processes.

The "biological clocks" make it possible for animals to orient themselves in time quite accurately. For example, birds of the sparrow family sense the beginning of new days with an accuracy to within 15 minutes. Most of the martlets in the Moscow region come back each year with amazing accuracy on the same day, namely the 17^{th} of May, and depart on the 11^{th} of August. In California the swallows return on the 19^{th} of March, and this day is considered the beginning of spring.

We know from our everyday experience that certain individuals have an amazing ability to sense time. They can determine the hour of the day exactly and without error, differentiate wall time intervals and duration of pauses, wake up in the morning at a given time without an alarm clock. Since as a rule the cosmonauts will be exposed to constant conditions in interplanetary flight, away from the usual geophysical inputs, it is of interest to evaluate man's ability to orient himself in time with the aid of the circadian rhythms, i.e., to use his "biological clock" in this situation.

Of interest in this connection are the results of experiments in isolation chambers and caves, where the subjects were not permitted to utilize clocks.

V. I. Myasnikov conducted the following experiment. The subject, placed in an isolation chamber, knew the duration of the experiment (seven days) but had no clock to monitor the passage of time and had no agenda to follow. According to his instructions he could sleep, eat, write in the logbook, do gymnastics, and so on whenever he wished. After several days the subject became disoriented in time, although the circadian rhythm of the physiological processes was maintained, and he prepared to leave the isolation chamber 14 hours ahead of the scheduled time. /232

In his experiment, Aschoff placed a group of subjects in a specially equipped bunker located far below the surface of the earth to prevent entry of sounds. The subjects were left completely to themselves. They turned out the light before going to sleep and turned it on when awakening, prepared their own food, and so on. Special equipment was used to make a continuous recording of the physiological functions of the subjects. The experiment showed that after 18 days the subjects "lagged behind" astronomical time by 32.5 hours, i.e., their days consisted of nearly 26 hours rather than 24. Variation of all the physiological functions in this same rhythm was characteristic for the subjects at the end of the experiment.

In an article entitled "Dialogue: Space-Earth," Academician V. V. Parin discussed an experiment conducted at the Max Planck

Institute. Three men were isolated in underground chambers. They had no clocks and their agenda was not regulated in any way. After a month one subject was eating lunch at the same time as another ate dinner, while the third started his breakfast for the next day.

In 1967 a group of eight Hungarian scientists spent a full month underground in one of the Buda Mountain caves. The expedition members had neither clocks nor radio receivers. When they received instructions by telephone to come to the surface it was found that the time calculations made in the cave lagged four days behind the actual time. In this case the "biological clocks" ran synchronously for all the members of the expedition for the first ten days and then there began to be discrepancies in the time orientation.

From this discussion we can conclude that although the physiological processes of man under constant conditions continue to retain for some time the circadian rhythmicity, the orientation without "time sensors" becomes unrealistic.

It appears that intracellular biochemical processes form the primary basis for regulation of the circadian rhythms. However, numerous experiments have shown that the regulation of the circadian rhythms in organisms having a nervous system is a function of the latter. Thus, in special experiments the German scientist H. Klug showed that in worms, arthropods, and other /233
invertebrates the regulation of the daily physiological function rhythm is accomplished by the nervous system. The most exact data on the center which controls motor activity rhythm in the course of the day in insects were obtained by the English investigator Janet Harker in experiments with cockroaches — a typical nocturnal insect. It was found that in these insects the role

of primary "biological clock" is played by the subpharyngeal ganglion, which secretes definite chemical substances. If a cockroach (previously exposed to conditions of continuous illumination and which therefore has lost its marked motor activity rhythm) has its own subpharyngeal ganglion removed and replaced by another ganglion taken from a rhythmically active individual, after several days the activity of the operated insect becomes clearly rhythmical, and this rhythm corresponds to that of the donor cockroach.

The physiological mechanisms of circadian rhythm regulation in the higher vertebrate animals are particularly complex. These animals also have simpler regulators which have an intimate connection with the metabolism, and more complex regulators which are regulated by the central nervous system. It has been found that even after removal of the brain large-hemisphere cortex the animals retain daily periodicity of sleep and wakefulness, daily rhythmicity of the variations of body temperature, exchange processes, pulse frequency, respiration rate, and other vegetative functions. Hence we can conclude that maintenance of the circadian rhythms in animals relates to the sphere of unconditioned reflex activity, which is more resistant to random variations of the environment, and that circadian regulation centers are located in the subcortical formations and in the stem part of the brain.

However, although living organisms are able to maintain the circadian rhythmicity, this does not necessarily mean that this frequency will be maintained under all living conditions. After all, the organism is an "open system" and is influenced all the time by the surrounding conditions and adapts to their changes.

This adaptation to constantly changing conditions of the environment is accomplished through the mechanism of the conditioned reflexes. Under their influence there is also adaptation of the unconditioned reflex activity to the changing situation, which includes in particular the circadian rhythm of the physiological functions.

In order to clarify the question of adaptation of the physiological functions under the influence of various factors in the human being, we shall turn first of all to the facts obtained in studying the influence of various daily routines when working under normal conditions on the earth.

Solov'yeva and Gambashidze observed subway workers who worked only on the night shift for a long period (from six to 12 years). The body temperature, pulse rate, blood pressure, stability of attention, and other physiological processes were studied. As a result it was found that in spite of many years of working exclusively at night nearly all the subjects had no change of the daily physiological function rhythm. The physiological function changes had a sinusoidal nature with a peak in the daytime (at 12-16 hours), i.e., when the subjects were resting, and a minimum at night (at 02-04 hours), i.e., when the subjects were working. In other words, their curves basically agreed with the familiar classical curves obtained for individuals following the conventional sleep-waking regime. /234

To clarify the psychological shifts under the influence of eight-hour work on the night, evening, and day shifts among linotypists, Volkhin and Kryuk studied the status of their hearing sensitivity thresholds and other functions of the organism.

It was found that the lowest values using the technique described were obtained during the night shift and the highest during the day shift, and the functional changes in the evening shift were intermediate. In brief, once again in this case there was no change of the psychophysiological functions because of night work.

E. I. Brandt and O. I. Margolina made studies of locomotive operating personnel and conductor teams accompanying freight trains. For the people in this field the days are broken down into sequential alternation of sleep and work, and without any strict schedule (or on varying schedules). In other words, here we have a typical example of disruption of the daily stereotype. The observations showed that in the course of several years of this unusual alternation of work and rest the organism adapts to the absence of a constant regime. This adaptation is expressed in the ability of the workers of the locomotive and conductor teams to go to sleep quickly at any time of the day or night, even when the daytime sleep during rest at the "turnaround" station preceded normal nighttime sleep at home. However, even this situation does not alter the normal curves of daily variations of the physiological functions.

We see that the geophysical factors (daylight and so on) and also the social environment (rhythm of life, operation of governmental, educational, and other institutions) have far greater importance for the individual than his own working rhythm, eating, and so on. This is convincingly shown by observations of people making long flights on jet liners into other regions of the earth with a timezone shift of 6-12 hours. Such a timezone change requires that the human organism readjust the biorhythmicity in accordance with the changed living conditions. In the course of several days after such a flight desynchronization phenomena are noted in all cases, i.e., the "day-night" /235 physiological cycle cannot change in a short time, since the internal endogenic clock ("biological clock") does not coincide with local astronomical time. In these individuals readjustment of the physiological processes in relation to the new conditions is accomplished in the course of several days (usually no more than 15 days). But as long as the two cycles, physiological and physical, are not synchronized, i.e., are not in agreement, most people, particularly the elderly, sense some physiological discomfort. At night they frequently wish to eat rather than go to sleep. During the daytime they feel drowsy.

As N. A. Agadzhanyan points out, for the first few days of the altered living pattern the organism is essentially split into an alert mind and a sleepy body.

Several scientists believe that in international conferences important questions should not be discussed nor decisions made on the morning of the first days after a long-distance flight in the easterly direction or in the evening after a flight to the west.

Observations show that athletes lose their "sports form" to some degree in the first days after a flight through four or more time zones. Some time is required to recover their form.

French scientists established (cited in Alyakrinskiy, 1967) that excessively frequent alteration of the circadian physiological cycle caused nervous stress in airplane crews making long-distance flights. Disturbances of the desynchronization type occurred in 78% of the pilots in the case of a time shift in the range of 4 - 5 hours. The same authors emphasize that adaptation of the organism to such perturbations is very difficult. Of the 78 pilots with sleep disturbance, adaptation was not observed in 53 individuals, while in 18 the sleep disruption increased markedly. This is the reason for the attempts which have been made abroad to schedule pilot hours on the airlines with account for the circadian rhythms of the pilots.

A large number of experiments indicate that light and temperature have the greatest influence on the readjustment of the physiological function rhythm of plants and animals under isolated conditions.

The experiments of O. P. Shcherbakova, conducted on monkeys, are very important in studying adaptation of the physiological functions of the higher animals to altered vital process rhythms.

The experiments were carried out over a period of a year in a specially equipped small house with artificial lighting. The physiological functions were studied using two-phase, shortened, lengthened, and other daily regimes. It was found, /236 for example, that when using the two-phase daily rhythm most of the monkeys developed the corresponding motor activity rhythm by the third day, and then by the 6 - 13th days two-phasedness develops in the temperature curve, pulse rate, respiration rate, and the dynamics of the other physiological functions.

Along with the development of space technology in the Soviet Union and abroad, experiments were initiated to study various daily activity regimes under conditions simulating space flight. In the Soviet Union the pioneer in this field was the group of scientists headed by F. D. Gorbov.

The present authors together with O. N. Kuznetsov and A. N. Litsov conducted experiments under isolation chamber conditions to study "inverted" (waking during the nighttime, sleeping during the daytime), fractional, and other regimes. The study was conducted in complete solitude, isolation from external light and sound stimuli, absence of two-way speech communication. Males ranging from 26 to 38 years of age, who had been through a complete clinical examination, participated in the experiment. The subjects followed a strictly regulated daily regime, which included performance of operator activity, active relaxation, and sleep. In the two-phase regime the subjects performed all these activities twice a day; in the three-phase regime they performed them three times a day.

As a result of the experiments it was found that the more man's life-activity regime deviates from the usual regime the more difficult it is to tolerate the change. The three-phase regime was particularly difficult. However, in general, when the conventional regime is replaced by a new regime the subjects re-establish their initial work capability level after three to five days and begin to sleep at the hours prescribed by the new schedule. But the corresponding adaptation of the vegetative functions (pulse, respiration, body temperature, exchange processes, and so on) occurs only on the eighth day and is not always completely terminated even at the end of the 15-day period. Of all the altered regimes studied by Gorbov and the present authors it appears that the most acceptable is the fractional regime with two-phase sleep. However, in the case of this rhythm none of the subjects noted objectively the termination of each cycle. They continued to measure time by conventional earth days.

On the whole, while for animals in the case of rearrangement of the daily regime the physical inputs (light, temperature, and so on) are of primary importance, for man, as quite rightly emphasized by Kuznetsov, more significant are the psychic activity, the volitional drive to perform the daily schedule, and the ability to reorganize oneself quickly in accordance with the changing situation. We found that adaptation of the physiological functions to the new rhythm is particularly difficult in those individuals who constantly try to imagine what is taking place at every instant of the day outside the chamber.(3) /237

We presume that in preparing the daily schedule for each specific interplanetary flight account will be taken for the number of crew members, volume of work, availability of rest space, and so on. It is not impossible that the rhythm of the space days will look about as follows: four hours of operator activity, four hours of active relaxation, and four hours of sleep. We have already discussed the basis for the four-hour space duty period. Therefore, in the remainder of the chapter we shall analyze the questions associated with active relaxation and the characteristics of sleep under space flight conditions.

ACTIVE RELAXATION AND CHARACTERISTICS OF SLEEP IN SPACE FLIGHT

Fatigue is a natural process of temporary reduction of work capacity as a result of some particular human activity. The accumulation of fatigue as a result of irrationally organized human work and rest leads to a qualitatively new state — over-fatigue.

The indications of fatigue are extremely varied and variable. Hearing sensitivity, vision stability, and so on may deteriorate

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(3) The collection of papers "Notes on Cosmonaut Work Physiology" edited by N. N. Gurovskiy and the papers from the symposium on "Biological Rhythms and Questions of Developing Work and Rest Regimes," which included articles and summaries of reports on the problem being discussed here, was published in 1967.

under the influence of fatigue. In the psychomotor activity we note deterioration of motion coordination, reduction of the speeds of simple and complex reactions. Loss of memory, difficulty of recall, deterioration in ability to divide and switch attention appear.

G. O. Yefremov, Ye. A. Derevyanko, et al. note that drowsiness is a very characteristic fatigue symptom. According to their data, in long flights on bomber aircraft the aerial gunners complain most frequently of drowsiness (56%), i.e., individuals performing monotonous work, while only 21% of the pilots have this complaint and only 18% of the navigators. The following pattern of fatigue symptoms is noted during long flights: general languor, weakness, drowsiness, noise and heaviness in the head, headaches, muscle and joint pains, inattention, indifference, irritability, itching of the eyes. Eighty-five percent of the crew members indicated the development of fatigue during long flights, and 65% of them complained of fatigue in every flight.

K. I. Platonov worked out an overfatigue classification, /238
the basis of which is the degree of intensity of the following symptoms: reduction of ability to function, appearance of previously absent fatigue under load, compensation for decrease of ability to function through will power, disturbance of sleep, reduction of mental functioning ability.

We know from experience in aviation psychology that marked overfatigue of the flight crew is a consequence not so much of intensified and stressful flight activity as it is of irrational organization of the work-rest regime.

Of great importance in restoring work capability is active relaxation, which includes not only physical exercises, sports, and so on, but the ability to switch from one activity to another. The tremendous work capacity of Lenin can to some degree be explained by his ability to utilize active relaxation, on which he wrote the following: "I recall very well that change of reading or work — from translating to reading, from reading to gymanstics, from serious reading to light reading — all this is of very great assistance."[4]

It is probable that after completion of their duty periods part of the cosmonauts' time during the hours of active relaxation will be occupied with various scientific experiments, analysis of the results obtained, and so on.

Change of the emotional state is very important in restoring work capacity. Sechenov indicated that important factors here may be enlivening of the mood, music, and so on. At the present time these questions are attracting the attention of psychologists and physiologists working in the field of engineering psychology. In "Music for All" by L. Stokowski we find the interesting thought: "There is no doubt that the influence of music is both psychological and physiological. Each cell has its own individual vibration frequency. If the vibrations cease the cell dies.... Perhaps music can activate these cell vibrations and intensify their vitality." (Cited in Ivanov, 1969, p. 102.) When we listen to music we tune ourselves to its rhythm by the rhythm of our muscles. This, in turn, may have an effect on the operation of the internal organs, altering the heart's rhythm and the respiration rates. The influence of music on the emotional sphere was known to the ancient Greeks. Pythagorus and Hippocrates recommended

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[4] V. I. Lenin, Complete Collected Works, Vol. 55, p. 209.

special forms of music to avoid anger, jealousy, longing, and bad dreams.

At the present time music is being introduced more and more in factories and offices as a rhythm stimulator under monotonous work conditions. Nor will the cosmonauts be able to get along without music in long space flights. /239

On the earth the entire world is presented to man in color. The influence of color on the psychophysiological processes is tremendous. This influence is considered in modern production in the design of industrial complexes. Today the latest subject for discussion is equipping factory shops with large screens made from a fiberglass material for the projection of varying colored images of the city scenery and nature pictures of various colors. The screens can be brought to life gradually, brightening up at midday and decaying in intensity in the evening. In all probability the rest areas of interplanetary spacecraft will be equipped to utilize the stereo effect to reproduce various natural landscapes, accompanied by the voices of summer and winter birds, chirping of crickets, and so on.

Two-way super-long-distance radio communication and television will play a very significant role in combating fatigue. With the aid of these facilities the cosmonauts will be able to keep up at all times with events on the earth, "attend" theaters, movies, stadiums, talk with their relatives and friends. It is important that all (or at least most) of the crew eat at the same time and, as a rule they should not spend their active relaxation in solitude. The intracollective contacts not only during work hours but also in their free time will have a favorable effect on the nervous system tonus, on the mood of the cosmonauts. For example, this is what Yegorov had to say about eating together in space: "We made the flight free of the restraint harnesses, sat down, rested on the couches, changing position, even exchanging places, turning as we wished. While eating our food we not only used our hands to put the food in our mouths but also tried to catch the food in our mouths in the weightless state. We did this, obviously, not only for the fun of it but also to become familiar with the weightless state. This was all very entertaining and we were laughing throughout the meal. During dinner we released the medical kit in front of us and it floated there. We called it our 'sputnik.' This gave us a few pleasant minutes during the flight."

The organization of normal sleep is very important under space flight conditions.

The study of sleep in the case of altered regimes under weightless conditions was initiated in the Soviet Union by a group of scientific personnel headed by F. D. Gorbov. We (Kuznetsov, Lebedev, Litsov, and Khlebnikov) made three series of experiments in order to separate the influence of factors of the altered daily regime and isolation itself: the first series was made with the conventional daily regime (eight tests); the second series was made with an altered regime (17 tests); and the third series was made with a mixed regime (initiation of the experiment in the usual regime and transition on the third /240 day to the altered daily regime). The transition to the altered regime was made upon a sudden command (two tests) and in accordance with a preplanned program (11 tests). The depth of sleep was evaluated on the basis of both objective and subjective indices. The former included: visual observation with the use of infrared equipment, listening to sounds in the chamber, analysis of autographic recordings (ratio of quiet five-minute periods [PQF] to the total number of five-minute periods and the duration of the resting interval), analysis of the pulse and respiration rate change, and also the brain bioelectric activity [BBA]. The subjective sensations were reported by the subjects in both their final reports and diaries.

The effectiveness of the integrated objective evaluation of sleep depth in our studies (Kuznetsov, Lebedev, Litsov, 1966) was confirmed by the high degree of correlation between good sleep and work capacity in the experiments with the normal and altered daily regimes.

In the normal regime sleep was good throughout the experiment for all the individuals of the experimental group, retaining the staged nature and alternation of periods of deep and superficial sleep which are typical under normal conditions (the drowsy stage was characterized by PQF to 75 - 90% and the arousal stage was characterized by PQF to 60 - 70%). For most of the subjects the sleep duration did not exceed seven hours a day.

In the shifted regime case (sleep from 14 to 23 hours), sleep was intermittent according to both the subjective estimates and the objective data. The periods of motor activity increase and decrease followed one another irregularly. Most often two-, three-, and four-hour cycles alternated. The primary difference on the autographic recordings was a marked decrease of the quiet periods in comparison with the normal regime. Considerable improvement of the sleep was observed on the seventh and eighth days of the experiment. In the second half of the experiment the sleepless hours were primarily the last two, which approached the characteristics of the normal regime.

The shifted regime with sleeping hours from 5 to 14 o'clock was tolerated considerably more easily, both subjectively and objectively. It is interesting to note that the two types of transition to the shifted regime which we tested were tolerated with different subjective difficulty. The first type, in which the transition was made by shortening the waking period (retire at 14 o'clock instead of 23 o'clock), was more difficult to accept and as a rule did not provide good sleep. A reduction of the work capacity was noted in the first days after such a transition. The second type (sleep moved back to 5 o'clock in place of 23 o'clock) was tolerated considerably easier. As a rule we noted good work capacity and good sleep in the first days after the transition.

In the first fractional daily activity regime case the two /241
sleep periods (from 23 to 2 o'clock and from 5 to 8 o'clock) coincided with the usual sleeping hours. In these periods we observed in the subjects low motor activity — PQF to 70 - 80%. In the sleep period from 13 to 16 o'clock the motor activity was high — PQF to 42%. In the second fractional regime case the two sleep periods did not coincide with the nighttime hours. The motor activity was minimal from 4 to 7 o'clock in the morning (PQF to 60 - 90%), somewhat higher in the sleep period from 14 to 17 o'clock (PQF to 45 - 88%) and highest from 20 to 23 o'clock (PQF to 38 - 80%). Similar results on motor activity dynamics were also obtained in analysis of the distribution of the quiet intervals.

The integrated study of the sleep changes for the various daily regimes, along with the study of the work capacity, made it possible to analyze the differences between the subjective difficulties in adaptation to the shifted and fractional regimes. In the shifted regime case the individual is forced to work during hours which are usually used for sleep. This presents complications in connection with the inertia of the developed daily stereotype. However, a favorable factor in this regime is the continuity of the sleep and waking periods. In the fractional regime case the main subjective difficulty lies in the intermittency, and disappearance of the alternation of the working day and nighttime sleep of sufficient duration. In the first fractional regime case the basic hours of sleep and wakefulness coincided in time with the usual hours. Therefore, adaptation to the first fractional regime actually reduced to the necessity to work for three hours at nighttime, and the sleep loss was compensated for in the daytime. The relative nature of contrasting a shifted daily regime to a more rigid fractional regime was apparent. The result of the second shifted and the second fractional regimes confirmed our hypothesis on their opposite importance in man's adaptation to an altered daily rhythm. The most marked change of sleep and work capacity was found in the second fractional regime, with the most unfavorable combination of frationation and shifting. In this case the sleep changes, on the basis of both the subjective and all the objective depth-of-sleep criteria used, preceded and determined the nature of the work capacity change.

Since only sound sleep leads to recovery of work capacity, conditions for getting a good sleep must be created aboard interplanetary spacecraft.

Experience in the eight-day American Gemini 5 flight showed that sleeping by turns in the work area is very difficult. Astronauts Cooper and Conrad, who used this regime, complained that the smallest noise, even turning the pages of the flight logbook, awakened them, since it was very quiet in the cabin in general. An area for cosmonaut rest is provided in the Soviet /242
Soyuz spacecraft. However, we should point out that the cosmonauts

must sleep under weightless conditions. Beregova had the following to say concerning the characteristics of sleep in the weightless state: "I slept well and soundly. They even had to wake me twice from the earth, activating the alarm signal. But there is also something different about this sleep. On the earth we are accustomed to sensing our body when we sleep. When I first tried to go to sleep after loosely strapping in, without tightening the harness to hold my body to the couch, I was not able to get to sleep. Only after tightening the harness to hold my body against the surface of the couch or seat could I get a good and sound sleep. So I had to do a little learning how to sleep in weightless conditions."

Our studies showed that four hours of sleep after eight hours of wakefulness make it possible to recover one's work capacity completely under isolation chamber conditions. However, when organizing the work schedule aboard the spacecraft it will be important to establish for each member of the crew strictly fixed hours of duty time, active relaxation, and sleep. There is no doubt that further experiments on the earth, and also experience in space flights, will make it possible to refine and work out optimal rhythms for the days in space.

CONCLUSION

At the very dawn of aerial flight Tsiolkovskiy wrote: "I believe in the brilliant future of mankind, I believe that mankind not only will inherit the earth but will also transform the world of the planets. From here, from the sphere of the Sun, mankind will settle the entire universe. Of this I am deeply convinced. This is the destiny of earthly man. He will transform many planetary systems." /243

The scientific predictions of the founder of cosmonautics are beginning to come true in our times. Mankind is now preparing to reach new goals in the great feat of conquering space. The scope of the scientific and technical problems developing in this field is broadening, and these problems are being worked on by thousands and thousands of scientists, designers, engineers, technicians, and workers.

One of the important problems is clarification of the capabilities of man to reflect adequately objective reality away from our planet. We have attempted to correlate the scientific data relating to the psychological aspects of the cosmonaut activity under the conditions of outer space. It is obvious that in this survey it has not been possible to encompass all the material relating to space psychology. Extensive research work still awaits us in this field. But there is no doubt that, no matter what the difficulties which await the people participating in the exploration of space, all the obstacles will be overcome and interplanetary flights will become a fact.

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